The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association
Western Orthopedic Association

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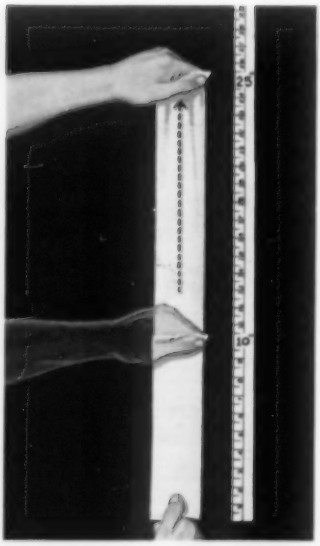

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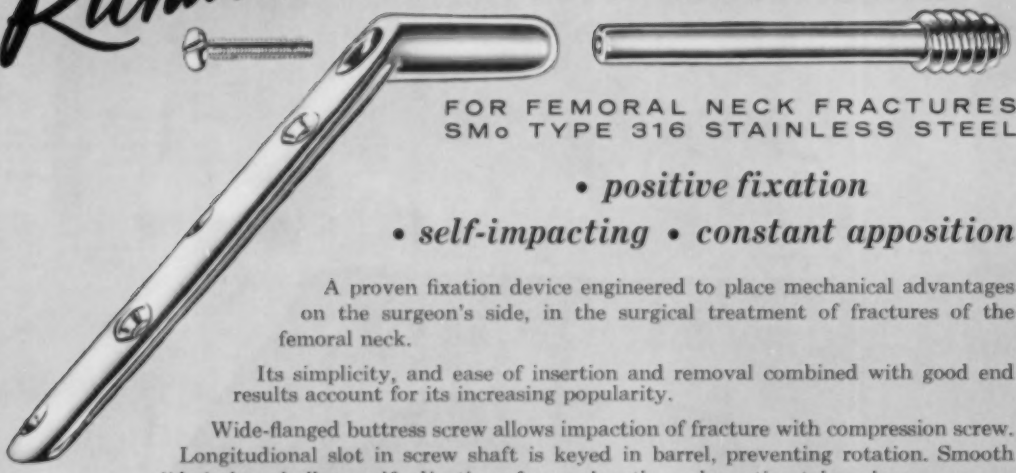

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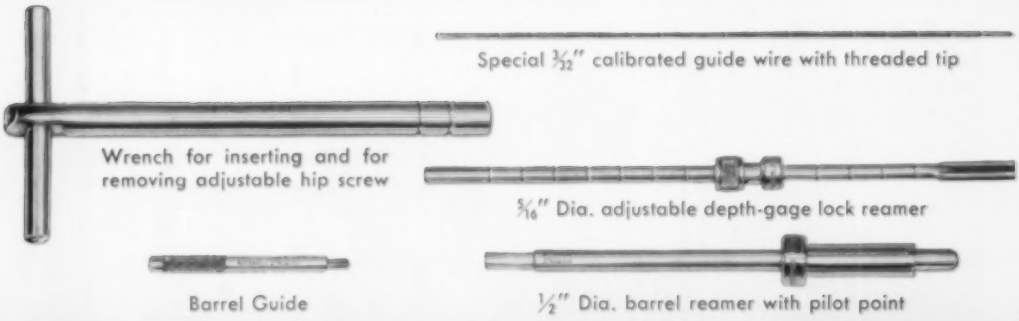

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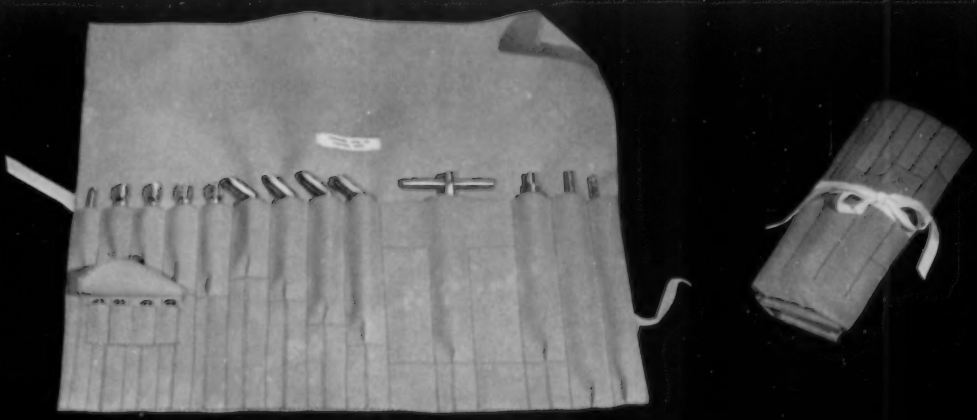

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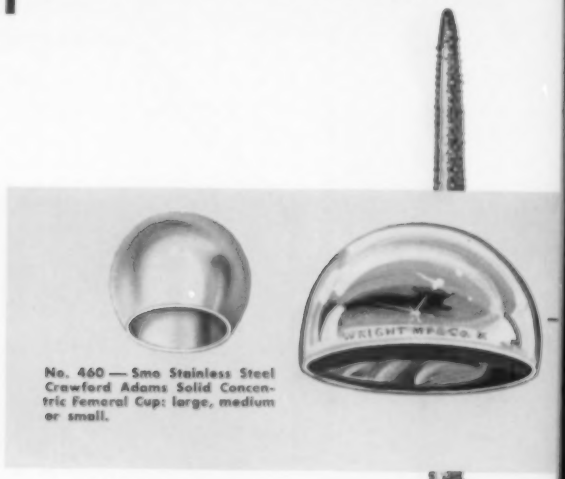

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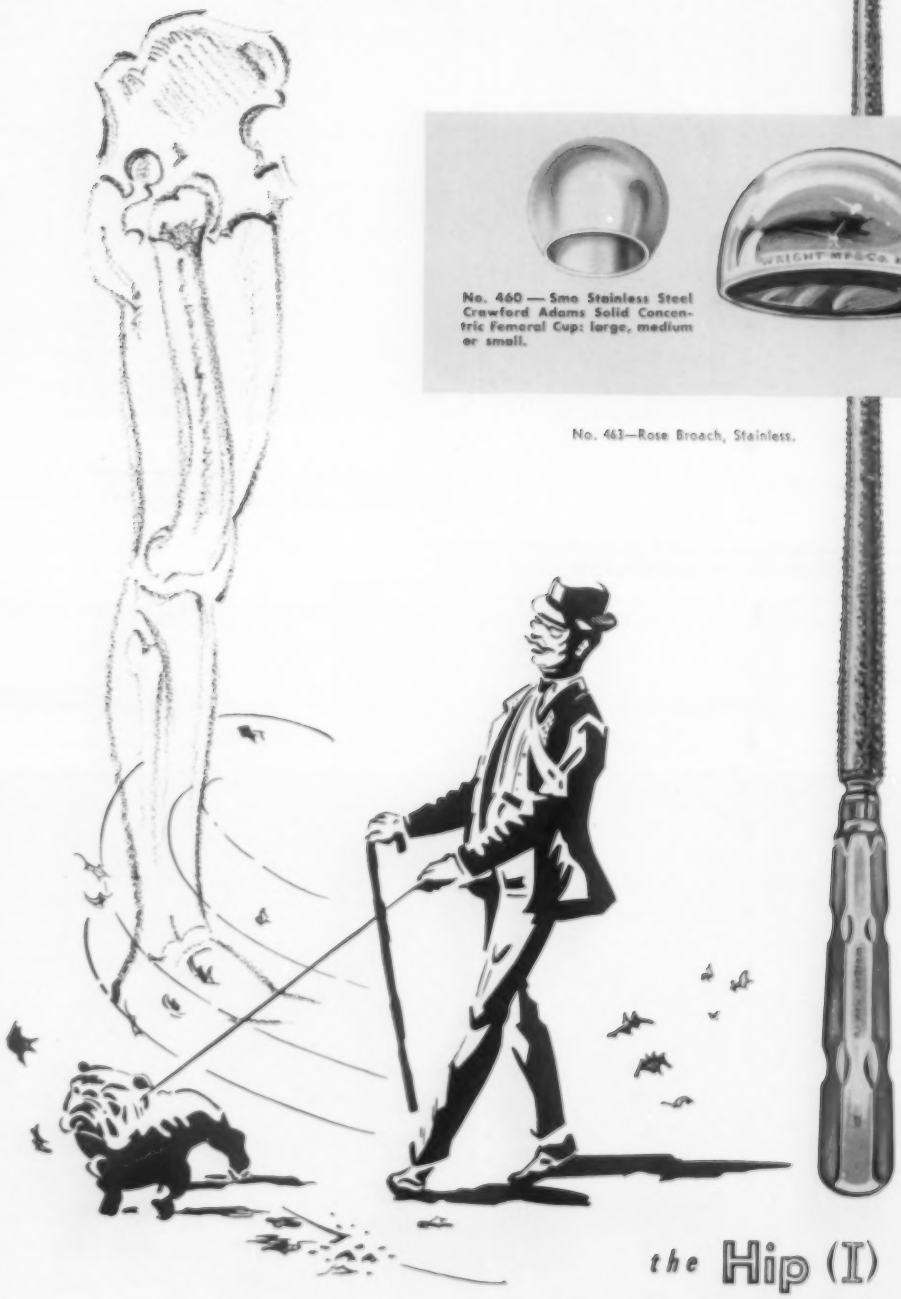

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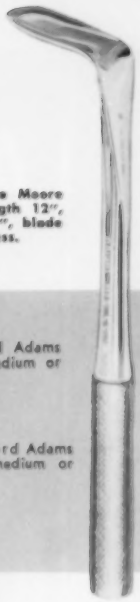

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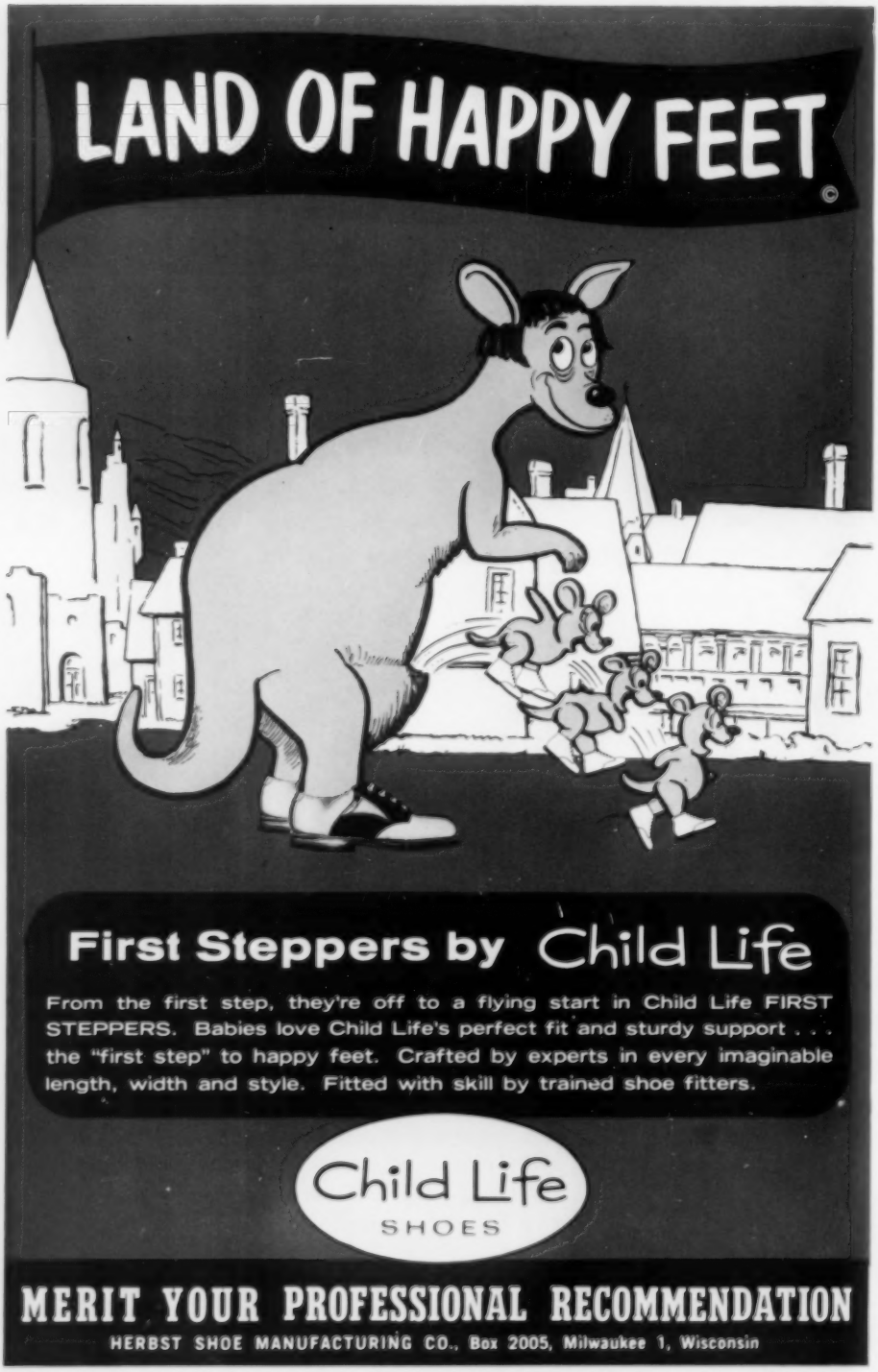
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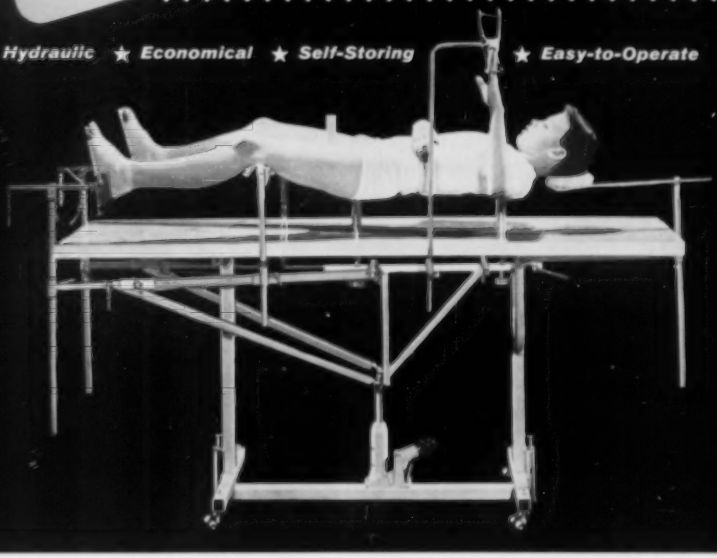

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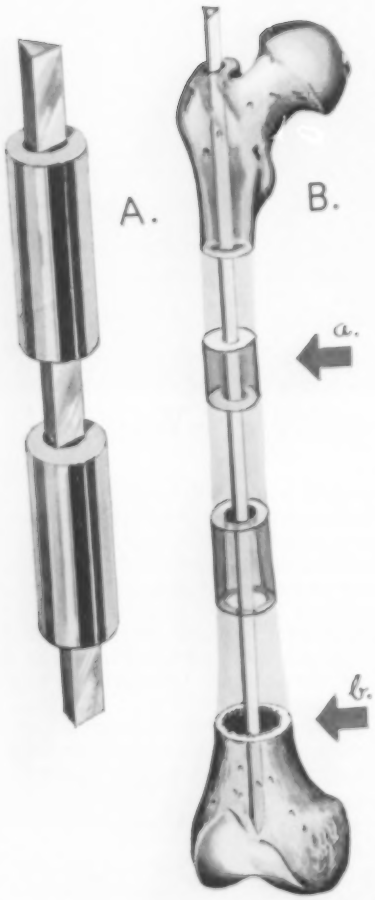


(A) A rod can be tightly impacted in a hollow pipe to control rotation because a pipe is of even contour and diameter throughout its entire length.

The medullary cavity of a bone, however, varies both in contour and diameter at various levels. A rod tightly impacted at one level will be loose at another.

(B) **Example femur.** A fracture of the upper half of the femur can be securely transfixed by any type of medullary rod because in this region, the bone is of fairly even diameter.

The medullary cavity is narrowest at the isthmus (a). The lower half of the medullary cavity is large and trumpet-shaped (b).

Any rod, which will pass through the isthmus (a), regardless of its shape in cross section, will be loose in the bone at (b).

Such a rod driven straight into the distal fragment must depend solely upon the doubtful firmness of the cancellous bone of the condyles for stability and the prevention of rotation of the lower fragment.

This is reliable only in young, active individuals. Cancellous bone has little substance in debilitated and inactive adults, and is almost absent in the elderly.

It thus becomes apparent that for stability of fixation of the lower fragment, the surgeon must depend not upon the irregularity of cross section of a straight rod, but upon the more dependable dynamic factors which can be utilized.

Femur Shaft Technics

For **precise** fixation the technic must vary at different levels because of the trumpet interior of the femur.

(A) Pinning not indicated except in young individuals.

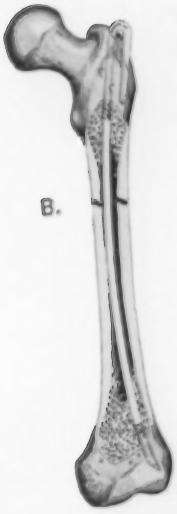
(B) Note modification of head of pin for stable fixation of upper fragment to prevent rotation and angulation.

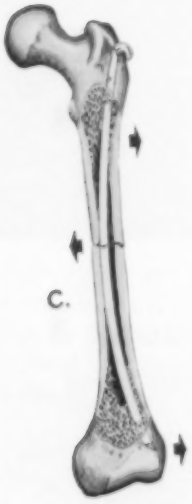
(C) Single curved pin gives stable fixation by 3-point pressure.

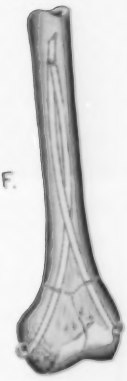
(D) Lower fragment is the problem. Addition of pin from internal condyle enhances stability.

(E) Bag of bones fracture fixed by double pins. Can usually be done as closed procedure. Spread of pins maintains length. Fascial envelope compresses fragments.

(F) Supra condylar and T fractures usually pinned as closed procedure.







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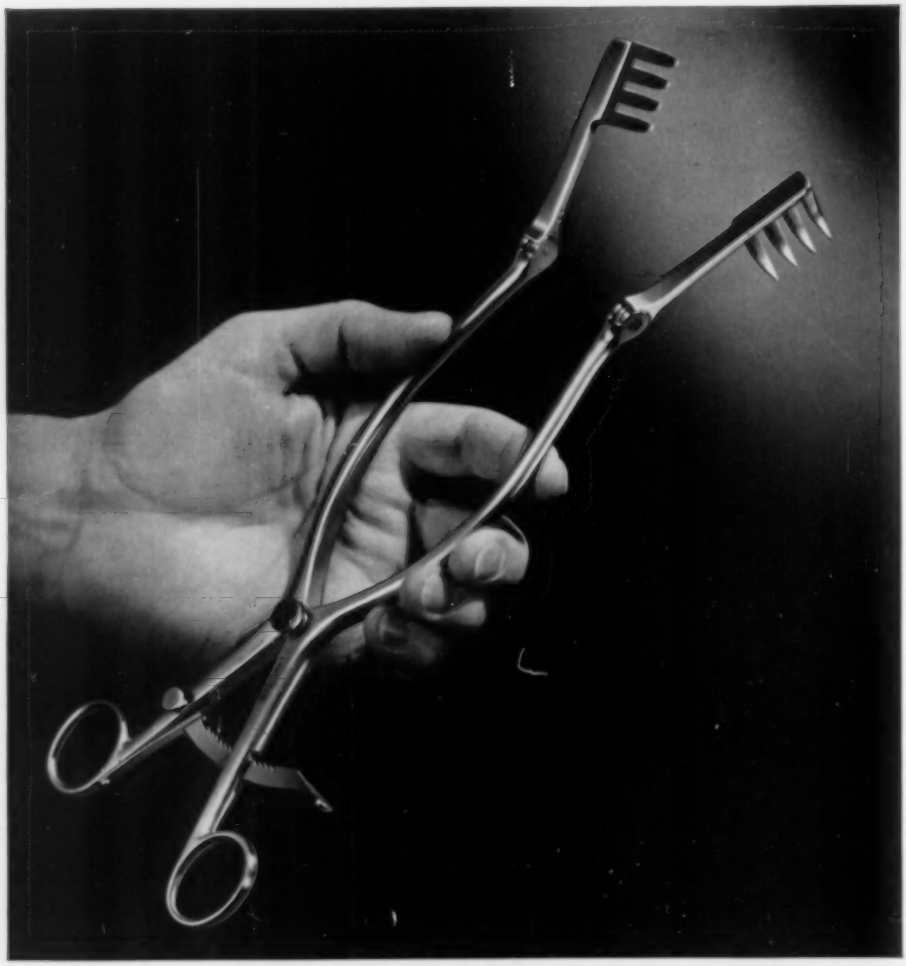

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1. Splitter, S.R.: Current Therapeutic Research 2:169 (June) 1960. 2. Harsha, W.N.: J. Okla. State Med. Assoc. *54*:12 (Jan.) 1961.

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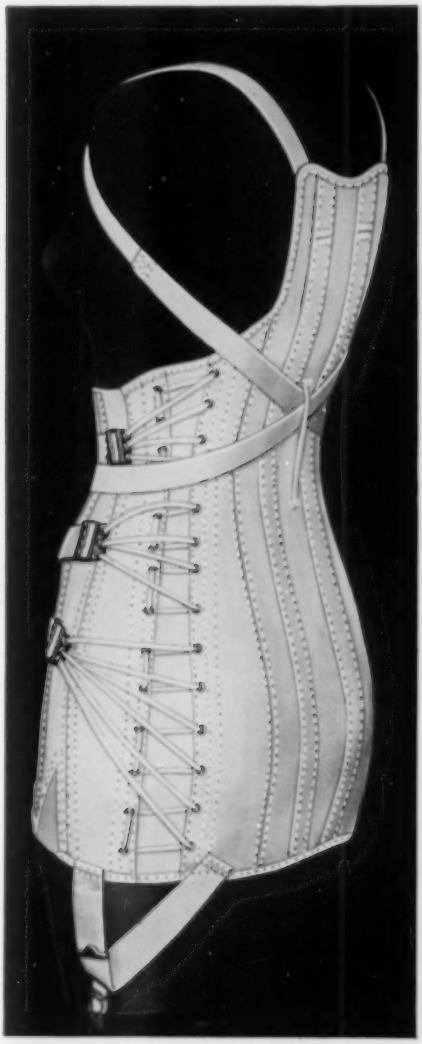

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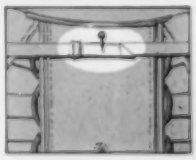

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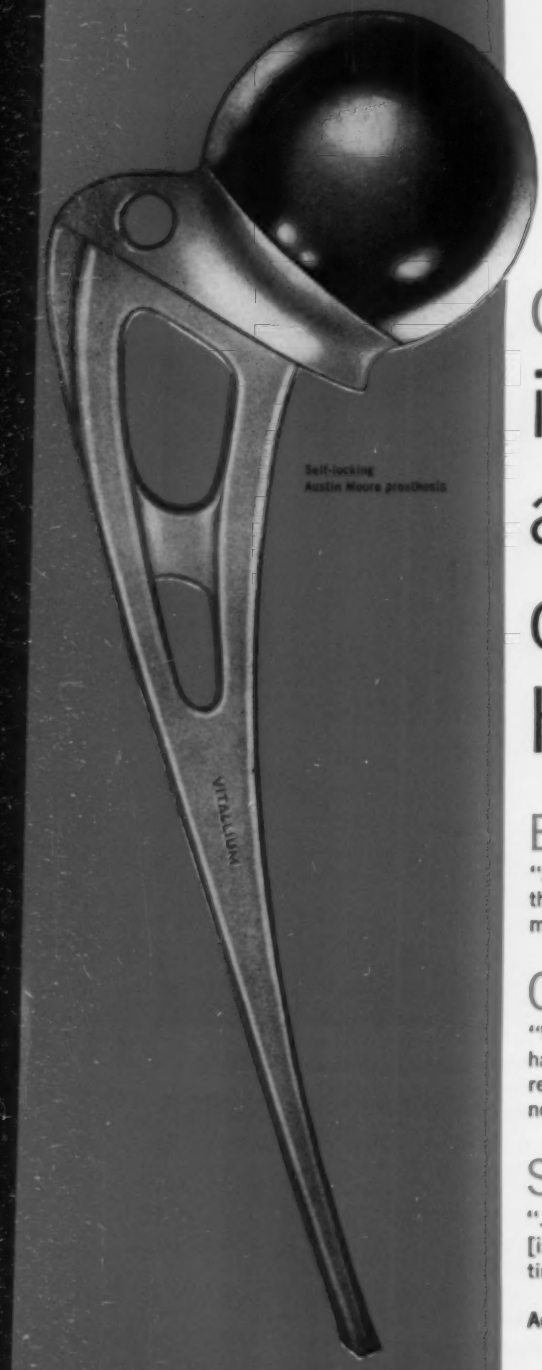

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REFERENCES: 1. Gaensler, F.G.: Wisconsin Med. J. 59:181, 1960. 2. Scales, J. T., and Zarek, J.M.: J. Bone & Joint Surg. 37B:527, 1955. 3. Matchett, F.: Rocky Mountain M.J. 56:47, 1959. 4. Callahan, J.J.: S. Clin. North America, W.B. Saunders Co., Philadelphia, Feb. 1957, p. 135.

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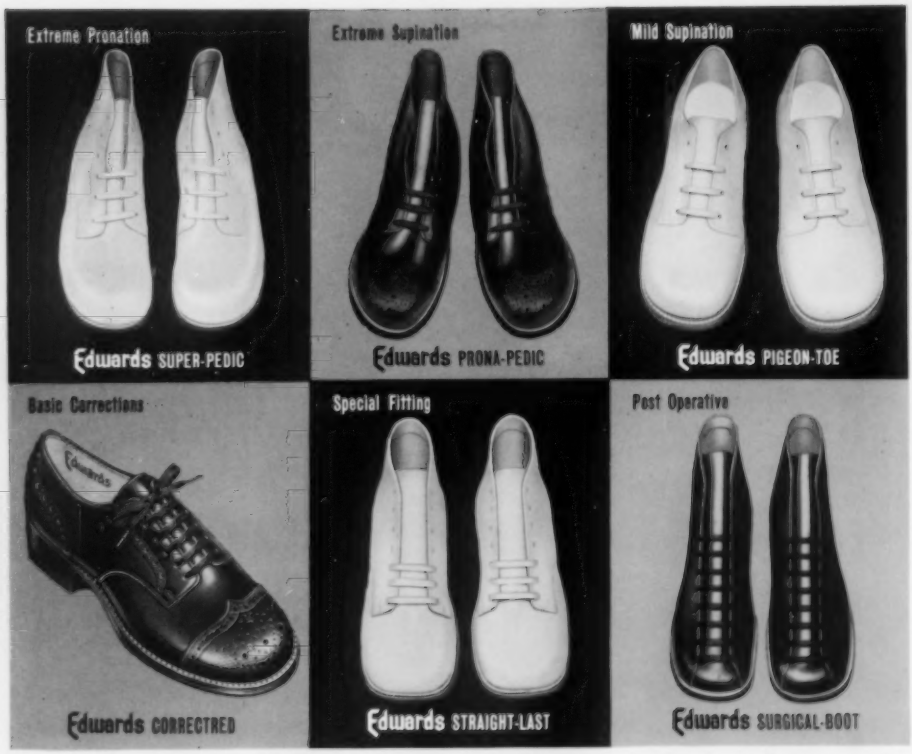

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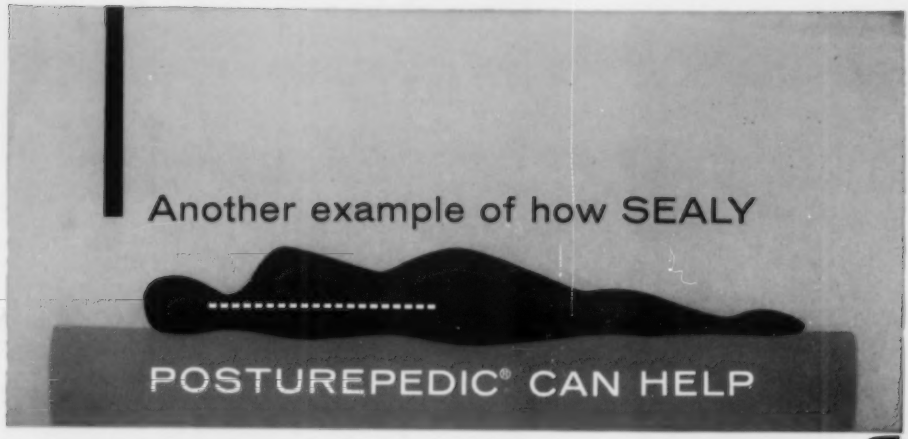

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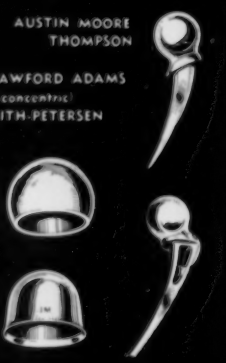

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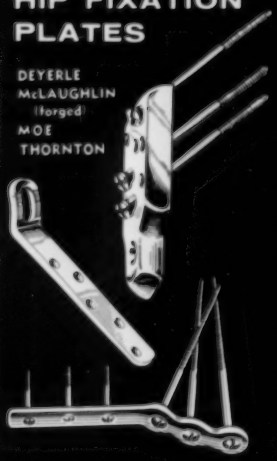

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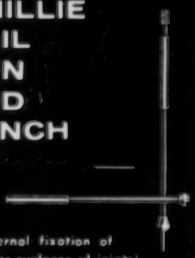

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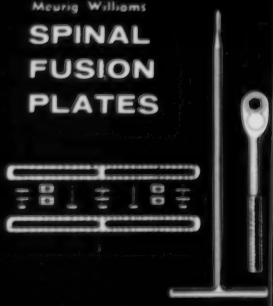

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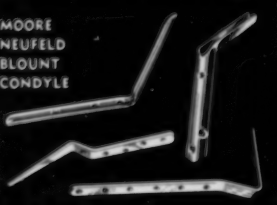

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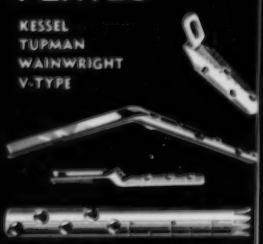

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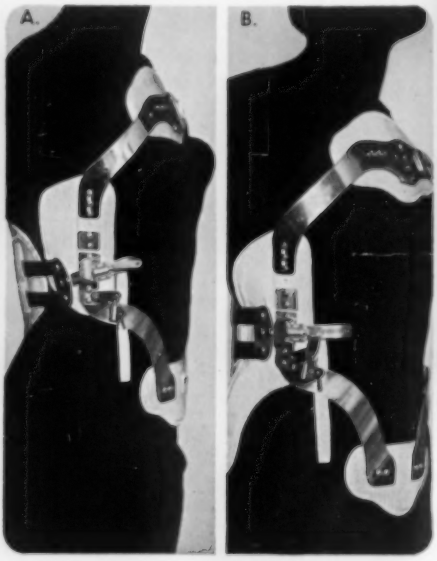

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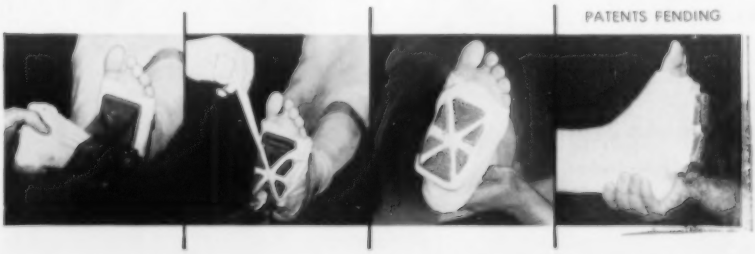

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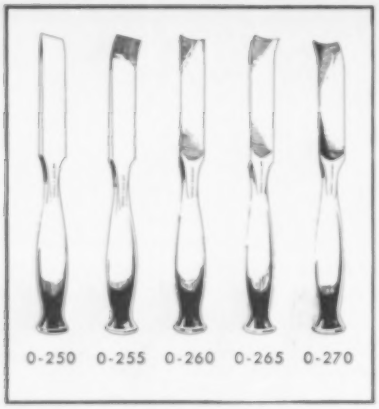

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*U.S. Patent No. 2,895,877

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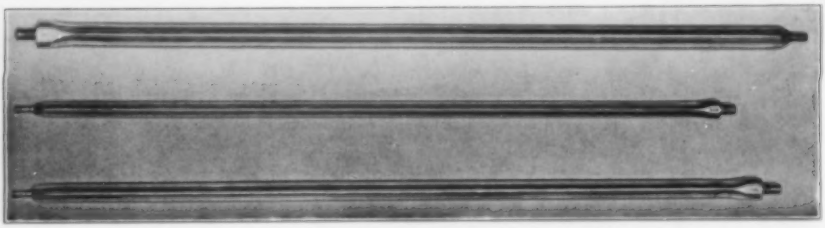

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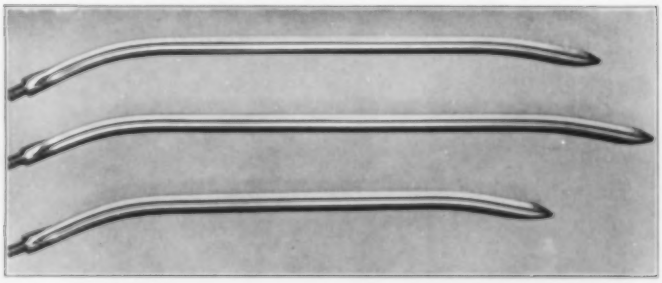

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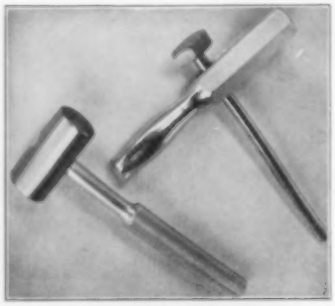

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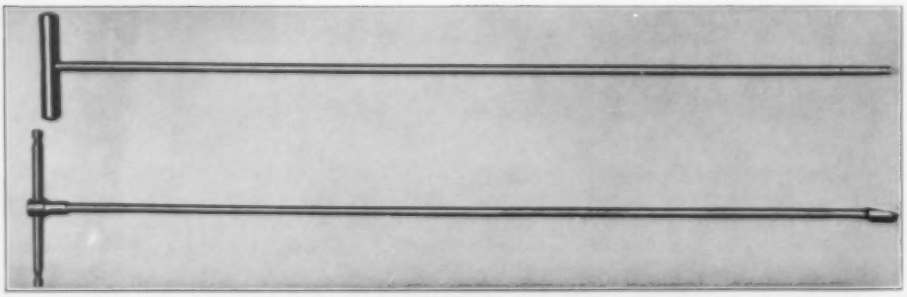

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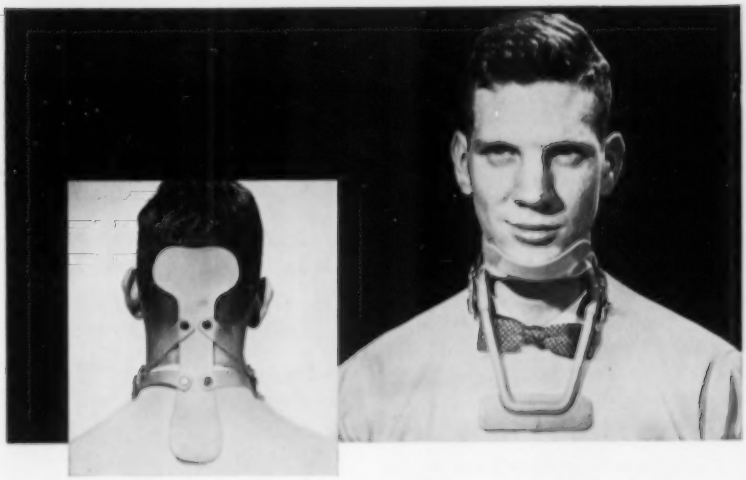

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*PATENT PENDING

[1]From Jackson, R.: The Cervical Syndrome, 2nd Ed., Springfield, Ill., Courtesy of Charles C. Thomas, Publisher, July, 1958, Pg. 155.

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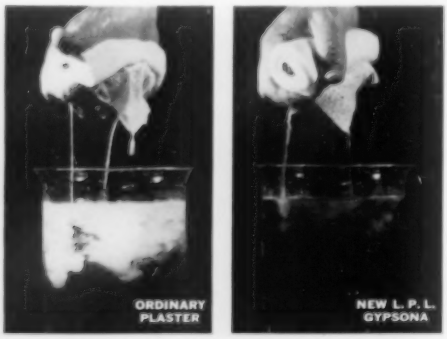
Until now, a tariff was paid to the drain bucket. Needed plaster strength was sometimes squeezed out, washed away.

Now, however, with the perfection of L.P.L. (Low Plaster Loss) Gypsona, you can mold 96% of the plaster into the finished cast. Now, newly developed adhesive agents securely anchor the plaster to the base cloth.



The difference is immediately apparent

Here you see two bandages being subjected to approximately the same amount of pressure after dipping. The disparity between the ordinary bandage and L.P.L. Gypsona is clearly evident. The Gypsona drainage is almost clear water.

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Most certainly, you will use fewer bandages—a cheery note for the keeper of the budget. There's less residue to contend with. You have cleaner handling throughout.

You also enjoy advantages that have long endowed the international prominence of Gypsona.

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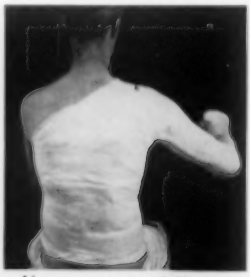
The deeply buried leno fabric molds firmly about bones, protuberances and indentations. The comfortable Gypsona creaminess, as always, is a pleasure to work with.



Now your most difficult plaster casts can be made with creamy smooth, extra strong L. P. L. Gypsona.

The threads do not slide. There is no sawtooth edge. The finished cast has the rich, polished glint that comes only of fine English-quarried plaster.

Price is still the same

Not to be overlooked is the ease of unwinding with the Gypsona plastic core, which prevents telescoping. Plaster stays fresh, almost indefinitely, in the airtight Gypsona package. And the price is still the same as standard Gypsona plaster bandages.

For a first-hand demonstration of L.P.L. Gypsona, get in touch with your Bauer & Black representative.

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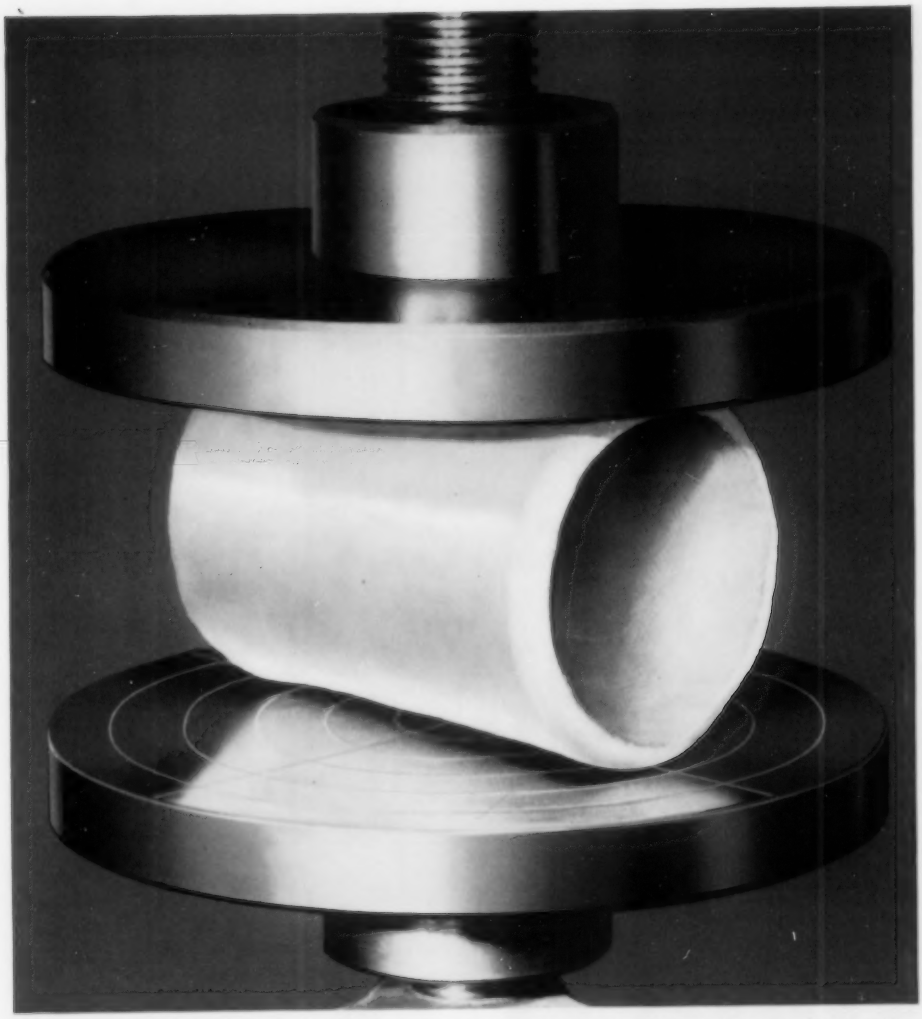

In the course of precision testing, a single L.P.L. Gypsona bandage, 4 inches wide and 3 yards long, was molded into a standard cylinder. After 24 hours, the cast was submitted to the strength-measuring apparatus above. The cast endured 304 lbs. pressure before it was crushed beyond a functional shape.

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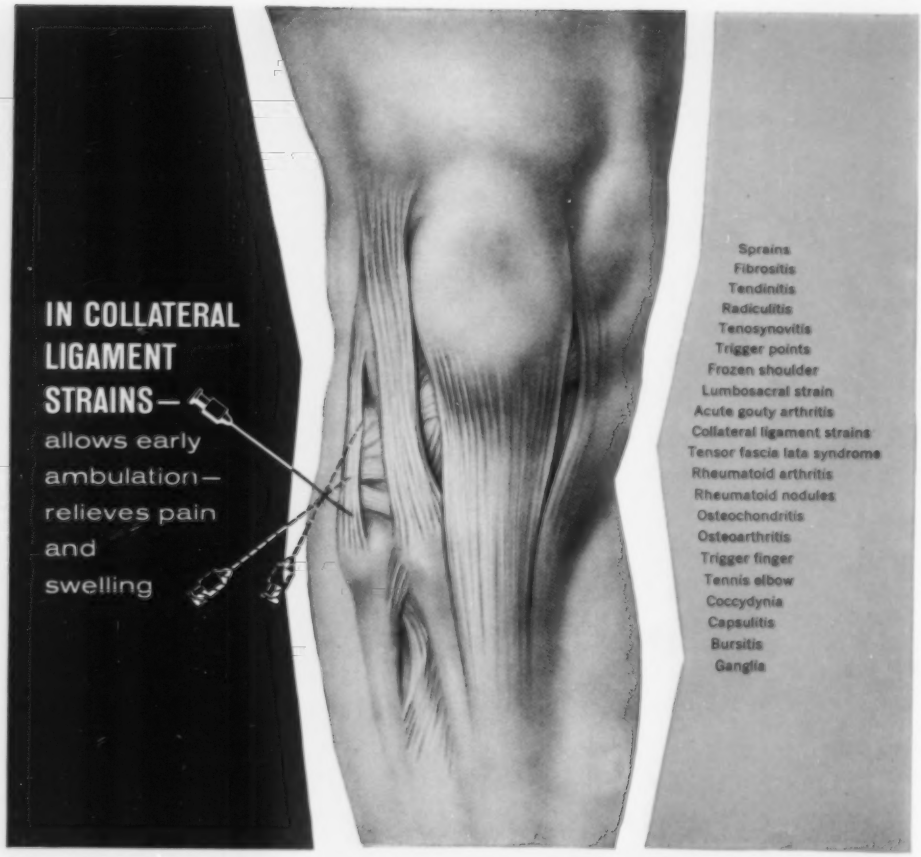

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References: 1. T. H. Harris, Dis. Nerv. System, 21:(Suppl.), 3, 1960. 2. J. Kinross-Wright, J. M. Cohen and J. A. Knight, *Ibid.*, p. 23. 3. J. W. Kelley and D. I. Gisveld, Colorado M., 2:3, 1960. 4. I. Hirshleifer, Curr. Therap. Res., 2:501, 1960. 5. H. K. von Kochenberg and H. L. Spiegelberg, Schweiz. med. Wchnschr., 90:1121, 1960. 6. M. Pechtoff, Clin. Med., 7:2313, 1960. 7. W. M. Benson and R. C. Schiele, Journal-Lancet, 80:579, 1960. 8. A. Voelkel, Med. exper., 2:170, 1960. 9. A. L. Schrobel, Am. Pract. & Digest Treat., 12:275, 1961.

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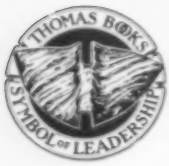

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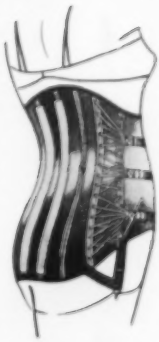

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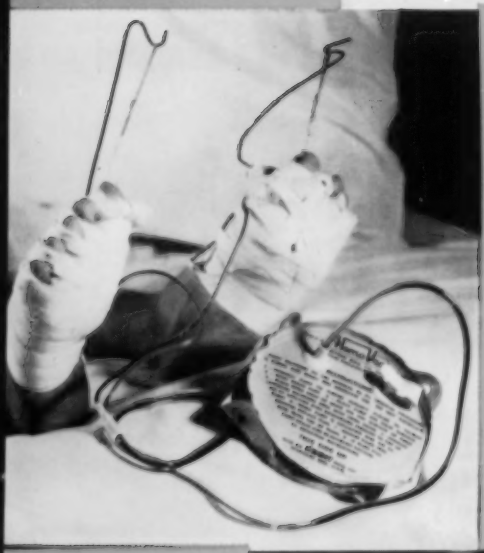

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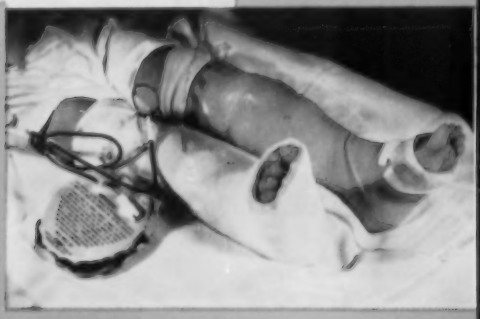

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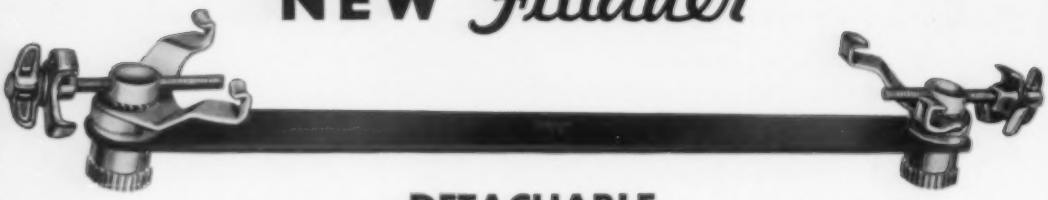

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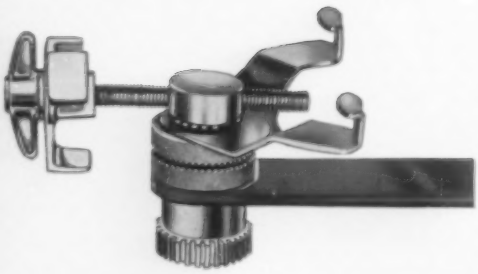

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Arthrodesis of the Hip

Review of 371 Cases *

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Despite current interest in various types of arthroplasty, arthrodesis remains the anchor of treatment for persistent painful unilateral disease of the hip in young and middle-aged adults. We suspect that such will always be the case. For a hip joint destroyed by tuberculosis or other infection, arthrodesis is still the treatment of choice in most instances. Similarly, one hip destroyed by rheumatoid arthritis may be best treated by arthrodesis if the other hip has retained satisfactory function or has had adequate function restored by arthroplasty in patients with both hips involved. Advanced degenerative disease of one hip, regardless of the cause, is usually best treated by arthrodesis in patients of middle age or younger who wish to live active, strenuous lives. Finally, many patients, after severe fracture-dislocation of the hip, eventually are treated by arthrodesis. Some of these patients should have primary arthrodesis to avoid prolonged disability.

It is the purpose of this study to review the results of arthrodesis of the hip at the Mayo Clinic with particular emphasis on the relation of the operative technique to the incidence of fusion.

HISTORICAL ASPECTS

Ankylosis of the hip, provided the hip is in good position for walking, is only moderately disabling and is much preferred by patients to pain and deformity. Arthrodesis was first used for old congenital dislocation by Heusner, by Lampugnani, and by Albert as early as 1885, according to Nové-Josserand. Albee is generally considered to have been the first to perform surgical arthrodesis in this country. After his report of five patients treated by intra-articular fusion for osteo-arthritis in 1908, scores of surgical techniques for arthrodeses were introduced. Until Ghormley, in 1931, and Henderson, in 1933, described their techniques (Fig. 1), most orthopaedic surgeons apparently believed that all surgical arthrodeses for tuberculosis of the hip should be performed in an entirely extra-articular manner. Ghormley pointed out that the risk of spreading tuberculosis

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by opening the superior surface of the capsule was minimal. Henderson recommended for tuberculosis of the hip clean removal of tuberculous tissue and combined intra-articular and extra-articular fusion.

Trumble, in 1932, and Brittain, in 1942, described techniques for ischiofemoral arthrodesis. For a time, many orthopaedic surgeons apparently thought that the Brittain operation was the method of choice; however, in recent years, this procedure has been generally abandoned although it still appears to be the procedure of choice in hips in which conventional procedures have failed to produce fusion and in which the acetabulum and femoral head and neck are markedly eroded.

FIG. 1

Types of surgical procedures commonly used for arthrodesis of the hip at the Mayo Clinic during the past forty years.

In 1938, Watson-Jones advocated internal fixation of the femoral head to the pelvis by a long Smith-Petersen nail. He considered that such fixation combined with immobilization in plaster of Paris materially increased the chances of successful fusion and shortened the time of immobilization. Using this technique, Lindström reported 95 per cent success in forty-one cases; he did not use a cast and kept his patients in bed for only six weeks after the operation. Watson-Jones and Robinson later reported an incidence of 94 per cent sound bone fusion in 120 patients who had arthrodesis of the hip for osteo-arthritis and had been observed for a minimum of five years. Immobilization in a double hip spica for at least four months was considered essential by these authors. The incidence of success

reported by Lindström and by Watson-Jones and Robinson is better than that in any other series [2,5,14,20]. The largest series, more than 500 cases, was reported by Lange, who claimed 85 per cent perfect results.

Osteotomy of the upper part of the femur combined with arthrodesis of the hip was employed by orthopaedic surgeons at the Mayo Clinic, and probably by others elsewhere, as early as 1926, primarily to improve the position of the extremity. In 1939, Farkas suggested osteotomy as a means of minimizing stress on the arthrodesis. Wilkinson, in 1946, and Thompson and Cholmeley, both in 1956, advocated routine subtrochanteric osteotomy for all patients having arthrodesis of the hip. Both Thompson and Cholmeley concluded that success occurred more frequently when the grafting operation was combined with or followed by osteotomy. Cholmeley stated that an upper femoral osteotomy frequently converts an unsuccessful extra-articular hip graft into a successful one without further grafting. Thompson noted a 90 per cent rate of union in those patients having combined hip fusion and osteotomy against a prior 26 per cent rate of union in patients having fusion without osteotomy for osteo-arthritis.

Charnley, in 1953, advocated central dislocation of the femoral head in surgical arthrodesis of the hip and subsequently reported excellent or good results in 88 per cent of 105 patients treated by this method [7]. Even though many of his patients did not obtain bone fusion by the central-displacement procedure they were freed of pain and hence were included in the 88 per cent good results. It is common knowledge that fibrous ankylosis following attempted surgical arthrodeses may relieve pain in the hips that have failed to fuse. Piggot reported solid bone fusion in 72 per cent of ninety-one patients treated by the Charnley procedure, but Mortens and Jensen noted bone fusion in only seventeen of thirty-nine patients having the same operation; however, thirty-three of these thirty-nine patients were better than they had been before operation.

PRESENT STUDY

We have determined the incidence of fusion in 371 patients who had surgical arthrodesis of the hip at the Mayo Clinic from 1914 through 1959. In this group there were 218 male and 153 female patients whose average age was 36.5 years. The youngest patient was four and a half years of age and the oldest was seventy-seven. Twenty-four of the patients were fifteen years of age or younger. Twenty-four were lost to follow-up after a few months. The remaining 347 patients were followed for at least one year. All had roentgenograms and most of them were re-examined. Of these 347 patients, 271 had bone fusion and seventy-six (22 per cent) failed to obtain union after the first operation. A second attempt at fusion was made in thirty of these seventy-six patients with resultant solid fusion in twenty-two. Only one patient had a third and fourth attempt, finally achieving union after the fourth operation.

There were twenty-four children fifteen years of age or younger in this series. In eighteen, fusion was performed for tuberculosis; in six of the older children (thirteen to fifteen years old) the procedure was carried out following septic arthritis. A Brittain arthrodesis was performed in three of the tuberculous hips. The other children had extra-articular or combined extra-articular and intra-articular procedures. Excluding the three Brittain procedures there were four femoral osteotomies done at the time of the initial arthrodesis. Bone fusion occurred in all of these hips; but in one girl, fourteen years old, the osteotomy had not united six months after operation and a bone graft was inserted. Solid fusion of the osteotomy was judged to be present two months later.

Internal fixation of the femoral head to the pelvis was used in four children—

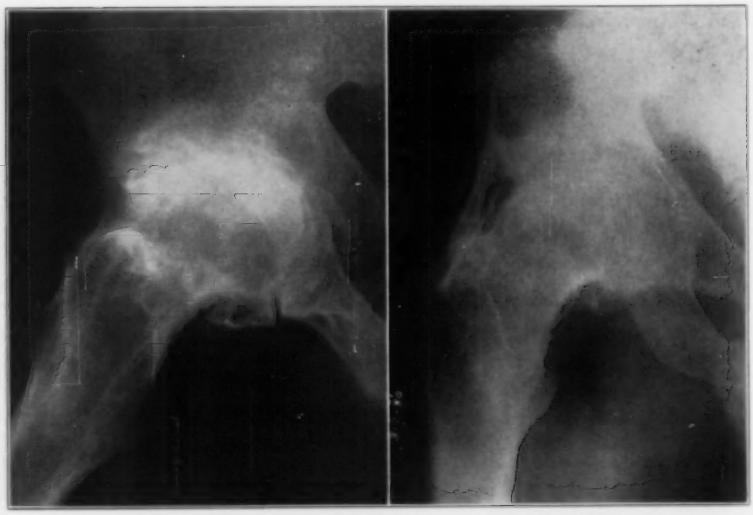

FIG. 2-A FIG. 2-B

Figs. 2-A and 2-B: Residuum of destructive arthritis (1938).
Fig. 2-A: Before operation.
Fig. 2-B: Appearance eight months after conventional arthrodesis, using the Henderson technique.

in the aforementioned girl with delayed union of the femoral osteotomy and in three other girls, twelve, thirteen, and fifteen years of age, who had conventional osteotomies. In all four hips with internal fixation, the arthrodesis was solid in from three to six months.

There were nine failures among the children in this series. Two followed Brittain procedures for tuberculosis. In one of these hips, solid fusion was achieved after a second extra-articular arthrodesis; in the other there was dense fibrous ankylosis, but the patient had no appreciable pain and no evidence of activity of the tuberculosis.

Three failures followed extra-articular arthrodesis for tuberculosis. One of these patients died of miliary tuberculosis four months after operation; the other two had second procedures with subsequent solid fusion—one after a Brittain procedure and the other after an extra-articular procedure.

Three failures followed combined intra-articular and extra-articular operations—one for tuberculosis and two for septic arthritis. Despite the lack of solid fusion all three of these hips had good fibrous ankylosis which allowed minimal motion without pain at the time of follow-up.

The patient with tuberculosis and fibrous union was last examined eight years after operation, at which time her disease was inactive. The other two patients were re-examined one and one and one-half years after operation.

The final rate of non-union in the entire group of adults and children was 15 per cent. In fourteen of the seventy-six patients with lack of fusion after the first operation, there was either drainage from the wound itself after operation or draining sinuses developed that were not in the wound. Ten of these fourteen patients had tuberculosis. In two of the tuberculous hips there were small draining sinuses at the time of operation.

Persistent drainage from tuberculous abscesses and sinuses was not uncommon prior to the introduction of antibiotics. Four of the fourteen patients with

TABLE I

ARTHRODESIS OF THE HIP

Etiological Conditions by Decades *

Condition	1920–1929		1930–1939		1940–1949		1950–1959	
	No.	Per cent	No.	Per cent	No.	Per cent	No.	Per cent
Tuberculosis	32	57	32	47	38	26	13	13
Destructive arthritis	15	27	19	28	33	23	22	22
Congenital dysplasia	1	2	2	3	14	10	12	12
Post-traumatic and degenerative lesions	8	14	15	22	58	41	54	53
Totals	56	100	68	100	143	100	101	100

* Three patients underwent operation prior to 1920.

drainage had a definite pyogenic infection of the operative wound that interfered with fusion; in one of these four, the infection might have been secondary to an old septic arthritis for which the arthrodesis was performed.

As might be expected in any series dating back to 1914, arthrodesis of the hip was performed more often for tuberculosis than for any other cause (Table I). Almost one-third (115) of the patients had tuberculosis of the hip. Whereas three decades ago, 57 per cent of the arthrodeses during a ten-year period were done for tuberculosis, less than 15 per cent of these procedures were done for this disease in the last decade. Destructive arthritis caused by infections other than tuberculosis accounted for 27 per cent of the arthrodeses thirty to forty years ago and still accounts for more than a fifth of these operations. Arthrodesis was performed for degenerative arthritis of the hip consequent to congenital dislocation in 11 per cent and consequent to dysplasia of the hip in 12 per cent of the patients in this series who required fusion during the past two decades. As might be expected, the

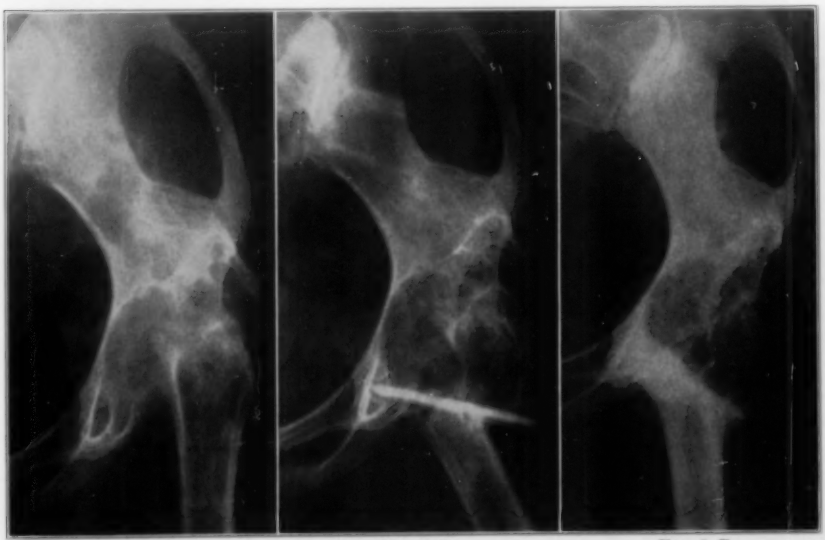

FIG. 3-A FIG. 3-B FIG. 3-C

Figs. 3-A, 3-B, and 3-C: Tuberculosis of the hip with failure of fusion.
Fig. 3-A: Before operation.
Figs. 3-B and 3-C: Appearance five months and two years, respectively, after a Brittain arthrodesis.

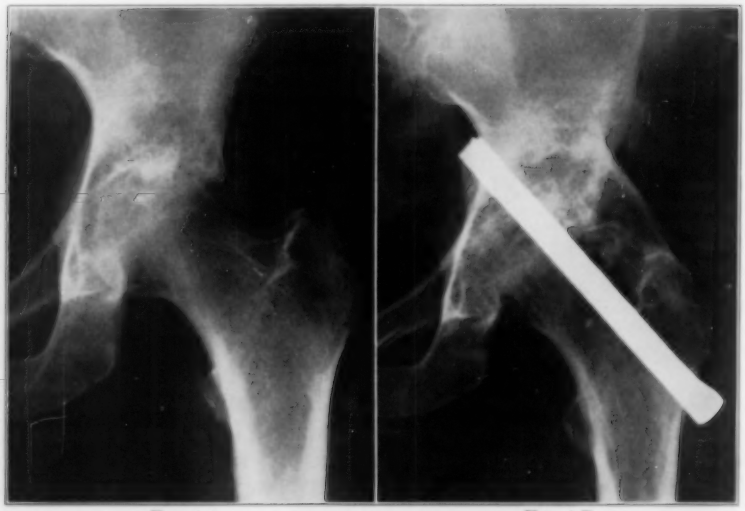

FIG. 4-A FIG. 4-B

Figs. 4-A and 4-B: Tuberculosis of the hip.
Fig. 4-A: Before operation.
Fig. 4-B: Appearance seventeen months after conventional arthrodesis by the Ghormley technique and internal fixation.

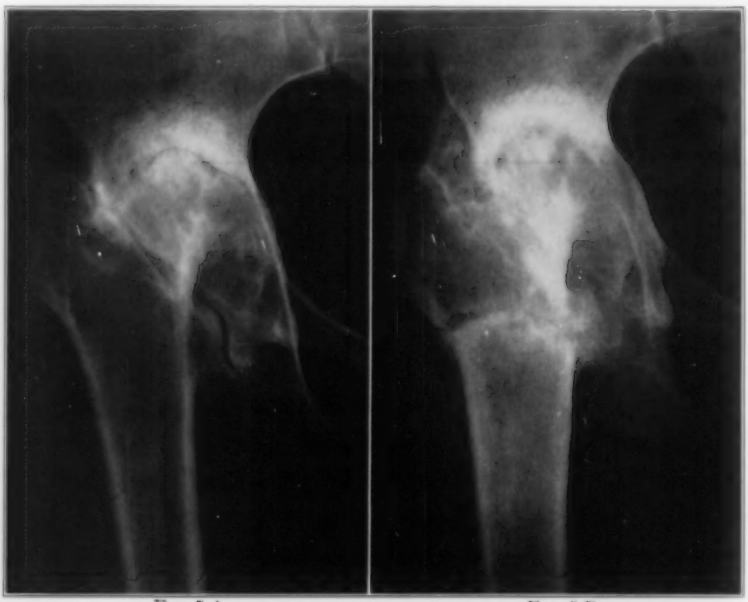

FIG. 5-A FIG. 5-B

Fig. 5-A: Fibrous ankylosis after previous conventional arthrodesis (1938).
Fig. 5-B: Appearance five months after placement of another bone graft and osteotomy.

number of fusions for post-traumatic and degenerative conditions has increased almost as rapidly as fusions for tuberculosis have decreased; more than half of these operations in recent years have been performed for post-traumatic and degenerative conditions.

FIG. 6-A FIG. 6-B

Figs. 6-A and 6-B: Severe fracture-dislocation followed by traumatic arthritis.
Fig. 6-A: Before operation.
Fig. 6-B: Appearance six months after intra-articular arthrodesis, bone-grafting, osteotomy, and internal fixation by the Thompson technique.

Many different surgical procedures and combinations of procedures were used in this series. The largest number of operations employed the techniques of Henderson and Ghormley (Figs. 2-A and 2-B) modified more or less by each surgeon. Since our primary interest was to determine the influence of internal fixation and osteotomy on the incidence of fusion, we did not attempt to analyze separately the results of the many techniques used in the 371 patients. Instead we classified as *conventional* the intra-articular, extra-articular, and the combined intra-articular and extra-articular procedures in which a bone graft was used across the hip joint. The procedures in which internal fixation, osteotomy, or both were added to a conventional procedure were classified separately. Ischiofemoral arthrodeses were also classified separately. These included two Trumble procedures; the rest were performed by the Brittain technique or a modification thereof (Figs. 3-A, 3-B, and 3-C), which consisted in intertrochanteric or subtrochanteric osteotomy of the femur with a free bone graft inserted through this osteotomy into an osteotomy in the ischium.

During the past fifteen years internal fixation has been used in most patients having arthrodeses (Figs. 4-A and 4-B) or in approximately one-third of the entire series. Devices for internal fixation used were Smith-Petersen nails, screws of various types, and Knowles' pins. Another group of patients had intertrochanteric or subtrochanteric osteotomy in addition to a conventional type of surgical procedure (Figs. 5-A and 5-B). This group did not have internal fixation. Since 1926, some of the orthopaedic surgeons at our clinic have fused contracted, deformed, and partially ankylosed hips by more or less disregarding the deformity until the malaligned joint was fixed by a bone graft across the joint, after which, but during the same surgical procedure, the alignment and position of the extremity were corrected by intertrochanteric or subtrochanteric osteotomy.

During the last few years, some of the orthopaedic surgeons at the clinic,

TABLE II

TYPE OF ARTHRODESIS OF THE HIP USED IN 371 PATIENTS

Type of Arthrodesis	Inadequate Follow-up	Total Followed	Result of First Operation: Union No.	Union Per cent	Non-union No.	Non-union Per cent
Ischiofemoral	0	22	15	68	7	32
Conventional with osteotomy	0	33	29	88	4*	12
Intra-articular and extra-articular with internal fixation and osteotomy	3	47	40	85	7*	15
Conventional with internal fixation	4	73	59	81	14	19
Conventional†	17‡	172	128	74	44	26
Totals	24	347	271	(78)	76	(22)

* Non-united osteotomy in three patients.
† Intra-articular, extra-articular, or combined arthrodesis.
‡ One patient died.

including one of the authors (P.R.L.), have routinely fixed the denuded femoral head to the freshened acetabulum with a large anterior bone graft fastened to the pubis and to the neck of the femur with five or six Vitallium or stainless-steel screws, as described by Thompson (Figs. 6-A and 6-B). Having done this they then eliminated stress from the long lever arm formed by the extremity by performing immediate subtrochanteric or intertrochanteric osteotomy. Although the method of fixation and placement of the bone grafts varied in this group of patients, all had combined intra-articular and extra-articular procedures in addition to internal fixation and osteotomy.

PROCEDURES

The operations performed on these 371 patients are summarized in Table II. Follow-up studies were available in 347 with the following results:

Twenty-two had ischiofemoral arthrodesis; fifteen of these (68 per cent) achieved union with bone.

One hundred and seventy-two had conventional procedures only; 128 of these (74 per cent) progressed to solid arthrodesis.

Seventy-three had conventional operations supplemented with internal fixation; fifty-nine (81 per cent) of these developed solid fusion.

Thirty-three had conventional arthrodesis combined with osteotomy; twenty-nine (88 per cent) of these gained fusion with bone.

Forty-seven had intra-articular and extra-articular fusion combined with both internal fixation and osteotomy; forty of these (85 per cent) had solid fusion after one operation.

The patients with both internal fixation and osteotomy were immobilized for four months in a single spica plaster-of-Paris cast that extended from the nipple line to just above the ankle on the affected side. Thereafter they were immobilized for an additional six weeks in a short plaster-of-Paris spica cast. Routinely, these patients were dismissed from the hospital two to four weeks after the surgical procedure, when they had learned to walk with crutches and partial weight-bearing, as suggested by Thompson. Subsequently, they were readmitted to the hospital for a change of the spica cast. The short spica cast was removed at the clinic where the patient was an out-patient.

The patients in this series, with occasional exceptions, regardless of the technique of fusion employed, encountered no great difficulty in regaining motion in the knee of the involved extremity and in the lumbar spine after this period of

TABLE III

ARTHRODESIS OF THE HIP FOR TUBERCULOSIS *

Type of Arthrodesis	No. of Patients	No Follow-up	Result Fusion	Result Non-Union
Ischiofemoral	16	0	13	3
Conventional and osteotomy	24	0	20	4
Osteotomy and internal fixation	1	0	1	0
Conventional and internal fixation	5	0	4	1
Conventional†	70	7‡	44	19
Totals	116	7	82	27
Second operation	13	0	10	3

* Total of 116 patients: sixty-four male and fifty-two female. Average age, 27.5 years.
† Intra-articular, extra-articular, or combined arthrodesis.
‡ One patient died.

TABLE IV

ARTHRODESIS OF THE HIP FOR DESTRUCTIVE ARTHRITIS (SEPTIC AND RHEUMATOID ARTHRITIS)*

Type of Arthrodesis	No. of Patients	Follow-up Inadequate	Result Fusion	Result Non-Union	Result Arthroplasty
Ischiofemoral	3	0	1	2	0
Conventional and osteotomy	7	0	7	0	0
Osteotomy and internal fixation	8	1	6	1 (osteotomy)	0
Conventional and internal fixation	18	0	14	4	0
Conventional†	54	2	41	11	0
Totals	90	3	69	18	0
Second operation	6	0	4	1	1

* Total of ninety patients: fifty-one male and thirty-nine female. Average age, 35.1 years.
† Intra-articular, extra-articular, or combined.

immobilization. In two instances, the femoral osteotomy was slow to unite, requiring as long as thirteen months for solid union to take place. In three patients non-union developed at the osteotomy site. In one instance the patient was immobilized in plaster for only eleven weeks. At that time immobilization was discontinued when the patient became agitated and maniacal because of claustrophobia. Despite non-union at the osteotomy site solid fusion of the hip occurred. It was recently learned that two years later this patient had bone-grafting done at the osteotomy site; internal fixation with a Smith-Petersen nail and a long plate attached to the femoral shaft obviated the necessity of external fixation. Her local orthopaedic surgeon, who performed the operation, stated that the patient is getting on extremely well.

Mortality

Only one death in the entire series of 371 patients could be attributed to the surgical procedure. This patient died from pulmonary embolism nineteen days after conventional arthrodesis. Another patient with multiple tuberculous lesions at the time of operation died of miliary tuberculosis four months after conventional arthrodesis. A third patient with tuberculosis died of amyloid disease three years after operation.

Tuberculosis

Of the 109 adequately followed patients who had arthrodesis for tuberculosis,

TABLE V

ARTHRODESIS OF THE HIP FOR CONGENITAL DISLOCATION AND COXA VARA *

Type of Arthrodesis	No. of Patients	Follow-up Inadequate	Result	
			Fusion	Non-Union
Ischiofemoral	0	0	0	0
Conventional and osteotomy	0	0	0	0
Osteotomy and internal fixation	7	1	6	0
Conventional and internal fixation	7	0	7	0
Conventional†	15	1	11	3
Totals	29	2	24	3
Second operation	1	0	1	0

* Total of twenty-nine patients: eight male and twenty-one female. Average age, forty years.
† Intra-articular, extra-articular, or combined.

eighty-two (75 per cent) had fusion after the first operation (Table III). In these patients, the incidence of fusion was slightly lower (70 per cent) in the sixty-three patients who had conventional fusions alone than it was in the patients who were treated by osteotomy, internal fixation, or both (83 per cent).

Destructive Arthritis

Sixty-nine (79 per cent) of the eighty-seven adequately followed patients who had arthrodesis for destructive arthritis caused by infections other than tuberculosis achieved union after one surgical procedure (Table IV). In these patients, the incidence of fusion was essentially the same as in the fifty-two patients treated by conventional fusion (78 per cent) and in the thirty-five patients treated by osteotomy, internal fixation, or both (80 per cent).

Congenital Lesions

Of the twenty-seven patients with adequate follow-up who had arthrodesis of the hip for congenital lesions (dislocation and coxa vara), twenty-four (88 per cent) had fusion after one operation (Table V). In this small group of patients, the incidence of fusion was distinctly less in the fourteen patients with conventional fusion (78 per cent) than it was in the thirteen treated by osteotomy, internal fixation, or both (100 per cent).

Trauma

Slipped epiphysis, fracture-dislocation, avascular necrosis of the femoral head, ununited fracture of the hip, failure of arthroplasty, or arthritis secondary to some other traumatic cause necessitated arthrodesis in eighty-four patients, four of whom could not be followed. Fusion occurred after the first operation in sixty (75 per cent) of the eighty patients who were followed (Table VI). In these patients the incidence of fusion was somewhat lower in the eighteen patients with conventional fusions (61 per cent) than it was in the sixty-two patients treated by osteotomy, internal fixation, or both (79 per cent).

Failure after Arthroplasty

Of particular interest were the sixteen patients in the traumatic group in whom previous arthroplasty had failed (Table VII). Thirteen had had Vitallium cups and three had had Austin Moore prostheses. Fifteen of the sixteen patients were followed adequately and of these, eleven (73 per cent) had solid fusion after the first surgical procedure (Figs. 7-A and 7-B). In the traumatic group there

TABLE VI

ARTHRODESIS OF HIP FOR TRAUMATIC LESIONS: SLIPPED EPIPHYSIS, FRACTURE-DISLOCATION, AVASCULAR NECROSIS, NON-UNITED FEMORAL NECK, FAILURE OF ARTHROPLASTY, AND TRAUMATIC ARTHRITIS FROM OTHER CAUSES *

Type of Arthrodesis	No. of Patients	Follow-up Inadequate	Result	
			Fusion	Non-Union
Ischiofemoral	2	0	1	1
Conventional and osteotomy	1	0	1	0
Osteotomy and internal fixation	25	0	21	4
Conventional and internal fixation	37	3	26	8
Conventional†	19	1	11	7
Totals	84	4	60	20
Second operation	8	0	6	2
Four operations	1	0	1	0

* Total of eighty-four patients: fifty-eight male and twenty-six female. Average age, 40.5 years.
† Intra-articular, extra-articular, or combined.

TABLE VII

ARTHRODESIS OF HIP AFTER FAILURE OF ARTHROPLASTY *

Type of Arthrodesis	No. of Patients	Follow-up Inadequate	Result	
			Fusion	Non-Union
Ischiofemoral	0	0	0	0
Conventional and osteotomy	0	0	0	0
Osteotomy and internal fixation	5	0	4	1
Conventional and internal fixation	8	1	6	1
Conventional†	3	0	1	2
Totals	16	1	11	4
Second operation	1	0	1	0

* Total of sixteen patients: eleven male and five female. Average age, 41.4 years. Thirteen Vitallium cups and three Austin Moore prostheses had been used
† Intra-articular, extra-articular, or combined.

were only three patients treated by conventional arthrodesis; only one of them achieved solid fusion. Twelve patients were treated by osteotomy and internal fixation or by a conventional procedure combined with internal fixation. Ten of these twelve hips fused. The four patients who failed to achieve solid fusion had fibrous union and were fairly comfortable. They have not yet experienced enough pain or inconvenience to submit to another operation.

Degenerative Lesions

Degenerative lesions of unknown cause (hypertrophic arthritis, osteoarthritis, and malum coxae senilis) were treated by arthrodesis in fifty-two patients, forty-five of whom were adequately followed. Thirty-eight patients (84 per cent) had solid fusion after the first surgical procedure (Table VIII). The incidence of fusion in the twenty-six patients with conventional fusion was 84 per cent, the same as it was in the nineteen patients treated by osteotomy, internal fixation, or both. The average age of this group of patients was almost ten years more than that of the patients with degenerative joint disease caused by trauma.

Three of the seventy-six patients in the total series who failed to obtain solid fusion after the first operation subsequently had arthroplasty. One of our best results after arthroplasty was in one of these patients.

TABLE VIII

ARTHRODESIS OF HIP FOR DEGENERATIVE LESIONS (CAUSE UNKNOWN): HYPERTROPHIC ARTHRITIS, OSTEO-ARTHRITIS, AND MALUM COXAE SENILIS *

Type of Arthrodesis	No. of Patients	Follow-up Inadequate	Result	
			Fusion	Non-Union
Ischiofemoral	1	0	0	1
Conventional and osteotomy	1	0	1	0
Osteotomy and internal fixation	9	1	7	1 (osteotomy)
Conventional and internal fixation	10	1	8	1
Conventional†	31	5	22	4
Totals	52	7	38	7
Second operation	2	0	1	1

* Total of fifty-two patients: thirty-seven male and fifteen female. Average age, 50.4 years.
† Intra-articular, extra-articular, or combined.

COMMENT

Selection of Patients for Arthrodesis

Arthrodesis of the hip is done most often in young and middle-aged adults having unilateral and incapacitating disease of the hip. Occasionally, particularly in tuberculosis, arthrodesis of the hip should be done in children. Some patients with disease of both hips are best treated by arthrodesis on one side and by arthroplasty, Girdlestone procedure, or Batchelor operation on the other. If arthroplasty is to be done on one side, this should be done first and the early results of this procedure assessed before arthrodesis is done on the other side. If less than 60 degrees of flexion is obtained in this hip after arthroplasty, we would hesitate to do arthrodesis on the opposite side.

With increasing experience we now believe that primary arthrodesis of the hip is indicated in certain fracture-dislocations of the hip incurred in high-speed automobile accidents, especially if reduction of the dislocation has been delayed forty-eight hours or more (Figs. 8-A, 8-B, and 8-C). Even a simple dislocation without fracture will almost inevitably lead to aseptic necrosis of the femoral head if not reduced within the first forty-eight hours. If there is a fracture of the femoral head or a severely comminuted fracture of the weight-bearing portion of the acetabulum associated with the dislocation, open reduction frequently will not restore adequate function and primary arthrodesis or arthroplasty may be indicated [19]. Similarly, with a severe central dislocation with comminution of the weight-bearing portion of the acetabulum, arthrodesis may be the procedure of choice. In the young laboring man arthrodesis is preferable to arthroplasty.

Selection of Type of Arthrodesis

For most patients requiring arthrodesis of the hip, a procedure utilizing the essentials to be enumerated in the next section is, we believe, the method of choice, although ischiofemoral arthrodesis or the wide-abduction procedure of Abbott may be necessary in some situations.

Although the results of ischiofemoral arthrodesis leave something to be desired from a statistical standpoint, there is no doubt that in selected cases the Brittain procedure is the method of choice [4,10]. If the upper end of the femur and the acetabulum have been extensively destroyed and eroded by infection, one can predict that the ischiofemoral fusion is more likely to be successful.

In non-tuberculous lesions in which the femoral head and neck are absent, as after removal of a prosthesis, arthrodesis may be accomplished by excising the

FIG. 7-A FIG. 7-B

Figs. 7-A and 7-B: Painful hip after use of an Austin Moore prosthesis.
Fig. 7-A: Before second operation.
Fig. 7-B: Appearance ten months later. The prosthesis was removed and arthrodesis, with bone-grafting, internal fixation, and osteotomy, was done

FIG. 8-A FIG. 8-L FIG. 8-C

Fig. 8-A: Severe fracture-dislocation of the hip of nine days' duration
Fig. 8-B: Primary arthrodesis was done, using the Thompson technique.
Fig. 8-C: Appearance five months later. The patient returned to work as a machinist at six months.

inferior half of the acetabulum and, if necessary, the lesser trochanter, followed by displacement of the denuded greater trochanter into the remaining denuded acetabulum (Figs. 7-A and 7-B). In such situations, the wide-abduction technique described by Abbott and Lucas is technically easier but has the disadvantage of requiring two surgical procedures [1,13].

Requirements for Successful Arthrodesis

It is our impression from the analysis of our cases that the best procedure for arthrodesis of most hips includes the following steps:

1. Transfusion of blood should be given. We have used from 1,500 to 2,500 milliliters of blood for the average patient and believe that our low mortality rate of 0.3 per cent depends, in part, on the liberal administration of blood.

2. The femoral head and acetabulum should be denuded of cartilage.

3. A large autogenous bone graft should be placed securely across the joint.

4. The femoral head should be fastened securely to the pelvis. We now favor use of a large bone graft across the front of the hip and fixation of the graft to the pelvis and upper end of the femur by several screws, according to the technique of Thompson. As an alternative, the femoral head may be fastened to the ilium by a Smith-Petersen nail, long wood screws, or threaded pins of various types.

5. In addition to the placement of a large graft, it is important to fill any dead space between the denuded femoral head and acetabulum with smaller grafts of cancellous bone.

6. Transverse osteotomy should be performed in the intertrochanteric or subtrochanteric portion of the femur to remove temporarily from the site of arthrodesis the stress created by the long lever arm of the extremity. It is not necessary and is probably inadvisable to displace the shaft of the femur medially, except when a Brittain arthrodesis is done. If the head of the femur does not fit well in the acetabulum with the hip in the desired position or if contracture of surrounding soft tissue is present to such an extent that it is difficult to place the femoral head in a good position for fusion with the extremity in the optimum position for function, the head should be fused to the pelvis in a partially corrected position and the alignment of the extremity corrected during the same surgical procedure at the site of the intertrochanteric or subtrochanteric osteotomy.

7. After arthrodesis, the most satisfactory position of the hip is neutral between abduction and adduction, flexion to 15 to 20 degrees, and neutral rotation or 5 degrees of external rotation. The extremity should not be placed in more than 10 degrees of abduction to compensate for actual shortening; more abduction than this results in an objectionable limp that is caused by the position of the extremity rather than the discrepancy in length.

8. Immobilization in a carefully molded plaster-of-Paris spica cast that extends at least from the nipple line to the ankle should be a routine part of the surgical procedure. If, for any reason, firm fixation of the femoral head to the pelvis cannot be obtained by internal fixation, the cast should be a double spica. Immobilization in plaster should be maintained until solid fusion of the hip and union of the osteotomy site are present. Immobilization for four months in a spica cast that extends below the knee and for an additional two months in a short spica is usually required. In some instances, the surgeon may wish to place the extremity in balanced traction immediately after the operation and to apply the first cast after the soft-tissue wound has healed. It is our opinion, however, that the patients are more comfortable if a cast is applied at the time of operation.

The patient should become active in bed and then start walking with crutches and partial weight-bearing to a limited extent as soon as possible after operation. The use of a single spica cast allows such early limited walking. Because early walking and activity, including quadriceps-setting exercises, have been common practice in this series during recent years, mobilization of the knee and spinal column has not been a particular problem in our experience. It must be realized, however, that some patients did not regain 70 degrees or more motion of the knee on the side of the operation for as long as one year after removal of the cast. It is a mistake to try to regain knee motion too fast; manipulation and passive stretching should be avoided. Intra-articular injections of hydrocortisone have been used in a few patients with stiffness of the knee and an effusion in the joint

after prolonged immobilization. It is our impression that mobilization is accelerated by use of the hydrocortisone, but this has not been studied systematically.

SUMMARY AND CONCLUSIONS

An analysis has been presented of 371 patients who had arthrodesis of the hip at the Mayo Clinic during the years 1914 through 1959.

Whereas thirty years ago most hip fusions were done because of tuberculosis of the hip, the majority now are done for post-traumatic conditions.

Arthrodesis of the hip can be expected to be successful in approximately 90 per cent of the patients if modern surgical techniques and principles are followed, including: (1) stimulation of osteogenesis by the use of massive bone grafts, (2) internal as well as external fixation of the head or upper end of the femur to the pelvis, (3) osteotomy of the femur just below the site of its fixation to the pelvis, thereby removing temporarily the stress caused by the great leverage exerted by the lower extremity, and (4) adequate and sufficiently prolonged external fixation.

Although the numbers of arthrodeses in the different disease categories in this series are too small to be significant, there are trends which are of interest. Ischiofemoral arthrodesis and conventional fusions (intra-articular or extra-articular arthrodeses or a combination of the two) seemed to result in a lower rate of fusion.

Subtrochanteric or intertrochanteric osteotomy, internal fixation of the femoral head to the pelvis, or both of these procedures, when combined with a conventional arthrodesis, seemed to increase the rate of fusion.

From the data available, there is little, if any, indication that the disease or condition requiring fusion influenced the fusion rate. The technique of fusion appeared to be the most important factor.

Arthrodesis, in our opinion, is the procedure of choice for most active young and middle-aged adults requiring an extensive reconstructive surgical procedure for one hip.

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DISCUSSION

Dr. Howard W. Schneider, Harvey, Illinois: The large series of cases reviewed by Dr. Lipscomb and Dr. McCaslin gives an adequate representation of all ages and all pathological conditions in which surgical ankylosis of the hip was used. The over-all percentage of failure of 22 per cent agrees with the figures given by Stinchfield and Cavallaro in their report of 117 cases from the New York Orthopaedic Hospital in 1950; they found 23 per cent over-all failure of fusion.

The 37 per cent non-union rate in children under fifteen years of age is also in accord with the general opinion that it is more difficult to obtain solid bone union in the younger-age groups. The authors' review of the history of this surgical procedure is of interest; it demonstrates the general trend toward internal fixation and the use of osteotomy as well as the attempt to cut down the amount of immobilization necessary after this very difficult surgical fusion. It is significant that internal fixation has been used in most of the patients operated on in the past fifteen years. I agree that the combined intra-articular and extra-articular procedure with internal fixation gives the best result. If adequate internal fixation of the hip joint is not obtained, certainly subtrochanteric osteotomy will reduce the stress caused by the leverage of the leg and allow better healing of the hip fusion. I wonder if it is the mechanical effect alone or if there is an additional biological stimulus caused by osteotomy of the upper end of the femur.

The main criticism of their most recent technique is the four to six-month period of immobilization in plaster-of-Paris casts. We orthopaedic surgeons should try to obtain a better method of internal fixation which would obviate the necessity for plaster casts and immobilization. Many surgeons in various parts of the world are working on this problem. I am sure that someone will devise some type of adequate internal fixation of the hip.

Charnley used the principle of compression arthrodesis with a large screw. My criticism of this is that the compression screw is usually so placed that it will not prevent flexion. If this compression screw is aimed in a more vertical direction up into the body of the ilium it might provide better fixation as well as better compression. This should give a higher percentage of fusions with the Charnley technique. A Smith-Petersen nail is not adequate to obtain solid fixation for arthrodesis of the hip, despite some optimistic earlier reports.

I have used a long intramedullary nail extending through the ilium down into the shaft of the femur to immobilize the hip joint adequately. The first operation was done eight years ago and I have subsequently done thirty-five similar procedures, using a medullary nail and an intra-articular fusion. This method of hip fusion allows the patient to be ambulatory on crutches without any form of external fixation; he can be discharged from the hospital by fifteen days after operation. Thus, the patient need not be denied the benefits of hip fusion because of excessive hospital expense or the risk of prolonged recumbency.

A curved four-flanged nail is used which extends from the posterior-superior spine through the body of the ilium, across the hip joint, into the medullary canal of the upper two-thirds of the femur. The nail traverses six inches of the body of the ilium and at least twice this length of the femur. The position of the nail in the ilium utilizes the strongest part of this bone and snug fixation is obtained by using the self-broaching type of nail which cuts its own bed in both the ilium and the femur.

I agree in general with the authors' requirements for successful arthrodesis. Their point about adequate blood transfusion is very important. As regards point 8, I would substitute adequate internal fixation for the spica casts.

(*Continued on page 979*)

Suction Drainage of Orthopaedic Wounds*

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Our interest in wound drainage arose from an appreciation of the role of the hematoma in the development of wound infections [1]. It has been difficult to ascertain the frequency of this association because, in essence, it is an evaluation of degree. Orthopaedic wounds are particularly vulnerable to the development of hematomata because of the problem of securing absolute hemostasis in operations involving medullary bone. Many approaches to this problem have been advanced. Wounds have been closed tightly to obtain a tamponade effect from the blood, and wounds have been closed loosely to allow the blood to escape. Drains of many forms have been used, but little study has been made of the amount, duration, and character of drainage to be expected from wounds. It seems reasonable that the most efficient method of removing blood and serum from a wound might be the use of a suction catheter [3,4,10,11,12,14,15].

This preliminary study concerns the initial 100 orthopaedic wounds in which silicone rubber suction catheters were utilized to secure drainage.

MATERIALS AND PROCEDURES

Catheters were fabricated from a medical grade of silicone rubber tubing with an internal diameter of one-eighth of an inch and a wall thickness of one-sixteenth of an inch. The tubing was cut in eighteen-inch lengths and six one-eighth-inch holes punched at half-inch intervals near one end of the tube. The catheters were all demonstrated to withstand suction of 120 millimeters of mercury and a linear pull of ten pounds without tearing at any of the holes. After testing, the tubing was carefully washed in detergent, rinsed in distilled water, soaked for twelve hours in isopropyl alcohol, and rerinsed w th distilled water to ensure removal of common surface contaminants prior to regular autoclaving [2].

At operation, the perforated end of the catheter was placed deep in the wound, as close to the source of bleeding or fluid accumulation as possible; the proximal portion of the tube was brought out through a small separate skin incision one-quarter of an inch long and so placed that the course of the catheter was as nearly straight as possible. The risk of kinking the tubing or encountering difficulty with removal was thus minimized.

A glass or plastic interconnector was used to attach the catheter to larger, sterile, polyethylene drainage tubing. A sterile dressing was placed on the end of the tubing if a brief interval was anticipated until the tubing could be attached to suction. If a plaster cast was to be applied, an asepto syringe or disposable plastic pump was used to provide suction and collect blood during the application of the cast.

In the recovery room the tubing was attached to a source of suction using a negative pressure of fifty or ninety millimeters of mercury. This was either the wall outlet of central suction or a Gomco machine. The amount of drainage while the patient was in the recovery room was recorded and a sample of the fluid retained for packed-cell volume determination.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Miami Beach, Florida, January 12, 1961.

TABLE I

DISTRIBUTION OF OPERATIVE WOUNDS

Operation	No. of Wounds
Vitallium-mold arthroplasty	23
Intracapsular and extracapsular hip fracture (repair)	18
Femoral-head replacement arthroplasty	17
Spine fusion (lumbosacral)	10
Hip fusion	9
Spine fusion for scoliosis	5
Hip osteotomy	3
Hip resection	3
Femoral-shaft fracture (repair)	3
Nail and plate removal	2
Hip osteoplasty (Heyman procedure)	1
Hip osteotomy (slipped epiphysis)	1
Hip disarticulation	1
Interscapulothoracic amputation	1
Excision of greater trochanter	1
Radical resection of quadriceps	1
Biopsy of femur	1

On transfer of the patient to the ward, similar suction equipment was utilized. The amount of drainage was recorded at eight-hour intervals thereafter until the drainage ceased or was negligible, at which time the catheter was removed. The original dressings were so placed that this could be accomplished without disturbing the dressing or making a window in the cast. At the time of removal, a routine swab was taken of the inside of the tubing for culture.

To provide a control series, 100 similar cases were paired with this suction-drained series. They were selected on the basis of underlying orthopaedic disease, previous surgical procedures, and associated diseases that could in any measure be considered to influence bleeding or wound healing, such as hypertension, arteriosclerosis, and avitaminosis, and steroid therapy. Either the same surgeon performed both operations or the surgeons were at a similar level of training and experience. The same number of patients, thirty-five, received prophylactic antibiotics in each series.

In an attempt to contrast drained with undrained wounds under controlled experimental conditions, bilateral hip resections were carried out in three dogs and bilateral iliac decortications in six rabbits. An attempt was made to secure as complete soft-tissue hemostasis as possible on each side with ligatures. Both wounds were closed tightly in layers, but the right was drained through a small separate skin incision by a silicone rubber catheter for twenty-four hours. The suction utilized was fifty millimeters of mercury for three rabbits and ninety millimeters for three rabbits and three dogs At the conclusion of this interval, the amount of fluid removed from the right side was measured and recorded. Both incisions were reopened and the wounds compared grossly and microscopically.

RESULTS

A series of 100 operative wounds in which a suction catheter was utilized for drainage was studied. The wounds selected were for operations performed in areas where perfect hemostasis is difficult to achieve and a hematoma is likely to develop (Table I). Thirty-five patients received prophylactic antibiotics consisting of penicillin and streptomycin or achromycin. Administration was started immediately postoperatively and generally continued for three to five days after operation.

TABLE II

BACTERIAL FLORA OBTAINED ON ROUTINE CULTURE OF CATHETER

Type	Number
Pyocyaneus	5
Staphylococcus (coagulase negative)	3
Staphylococcus (coagulase positive)	2
Aerobacter	3
Escherichia coli	2
Bacterium subtilis	1
Proteus	1
Clostridium welchii	1

TABLE III

DRAINAGE IN RELATION TO TIME AFTER OPERATION

Time of Drainage after Operation (*Hours*)	Mean Volume (*Milliliters*)	Mean Packed-Cell Volume (*Per cent*)
Recovery room: 2–12 hours	126	39*
Ward: first 8 hours	89	33
Ward: second 8 hours	58	18
Ward: third 8 hours	58	17

* Mean preoperative systemic packed-cell volume, 44 per cent.

In these 100 wounds there were three complications—two hematoseromata and one infection. The two hematoseromata were sterile and developed late following femoral-head replacement arthroplasty when the patients began to walk. One did not respond to simple aspiration and required open drainage.

The wound infection occurred after radical resection of the quadriceps for fibrosarcoma. The large incision was drained for sixty-five hours by a single catheter, but only seventy-five millimeters of fluid was collected. On removal of the catheter, the routine culture obtained from the inside of the tubing by a swab grew *Staphylococcus pyogenes*. On the sixth postoperative day, twenty millimeters of seropurulent fluid was released from the undrained portion of the wound. Organisms were cultured from this fluid identical to those cultured from the contents of the catheter. Subsequent healing of the wound was prompt and uneventful.

In all, there were seventeen positive cultures from the inside of the catheters, one being mixed coliform flora (Table II).

As noted, in only one of these wounds did a clinically obvious infection develop; however, in the seventeen cases, the patients' mean daily maximum temperatures were about one degree above the average level of similar suction-drained cases with negative cultures during each of the first four postoperative days. In contrast, in the undrained control series there were three wound infections which were considered to be major complications.

An assessment of wound healing is necessarily subjective since there is no suitable yardstick to measure the amounts of healing. However, it was our impression, based on examination of each wound, that healing was normal in every wound except the three with complications. Of interest, in this regard, was the lack of tension on the skin sutures, apparently reflecting the decreased distension in the incisional area.

The amount of fluid removed varied from 1,000 milliliters to sixty milliliters.

TABLE IV

MEAN MAXIMUM DAILY TEMPERATURES (RECTAL)

Time	Group	
	Series (*Degrees Fahrenheit*)	Control (*Degrees Fahrenheit*)
Before operation	99.6	99.3
Day of operation	99.8	100.1
1 day after operation	101.0	101.2
2 days after operation	101.2	101.2
3 days after operation	100.8	100.7
4 days after operation	100.2	100.4

with a mean of 353 milliliters and a median volume of 310 milliliters. Table III shows the mean volumes obtained as correlated with the mean packed-cell volumes. Catheters were normally removed when drainage became insignificant, usually in twenty-four to thirty-six hours.

There was no apparent correlation of the age of the patient and the amount of drainage; however, marked variation existed in the amount of fluid withdrawn in each type of procedure, and a previous surgical approach increased the amount of drainage, as did difficulty with hemostasis at the time of surgery. In general, hip fusions were most productive of drainage and nailed intracapsular hip fractures and femoral-head replacement arthroplasties least. In twelve wounds with minimum drainage the catheter was found to be partially obstructed by a non-adherent clot at the time of removal. Whether ninety or fifty millimeters of mercury suction was utilized for a given wound did not appear to influence the volume obtained.

Maximum daily temperatures in these patients on the day before operation and on the first four days after operation were compared with the temperatures of a control group of 100 paired cases. (Associated cardiac and pulmonary disease added complicating variables which could not be entirely excluded in this temperature comparison.) The mean maximum temperatures in the two groups are almost identical, as shown in Table IV.

There were three patients, in one of whom a bilateral hip reconstruction was required and in the other two of whom multiple-stage spine fusion for scoliosis was done, who provided a small but well controlled series. In each patient the temperatures were lower following the drained procedure—particularly on the first postoperative day when the mean difference of the three cases was 1.4 degrees. Following one of the undrained stages in fusion for scoliosis, a hematoma evacuated spontaneously on the seventh day.

In the twenty-four procedures in which bone grafts were used there was no roentgenographic evidence of interference with the progress of solid fusion. All grafts were incorporated with fusion in the usual time. The healing of the three fractures of the femoral shaft was satisfactory; there has been no suggestion of delayed union in the fractures treated by suction drainage of the fracture site. Eight patients in whom an iliac graft was taken at lumbosacral fusion and the entire area drained seemed to have less pain over the donor site than comparable patients in whom drainage was not used.

In six of the experimental animals, hematomata were found in the undrained wounds when they were opened in thirty-six hours, whereas relatively little fluid had collected in the region of the resected hip joint or decorticated ilium when subjected to suction drainage. However, the volume of the hematoma in the undrained wounds was consistently less than the volume of the fluid collected by suction from the drained wounds. Gross examination of the drained and undrained wounds and

FIG. 1

Photomicrograph of the undrained decorticated left iliac crest of a rabbit at three days showing hemorrhage, cellular infiltration, and separation of muscle from bone (×65).

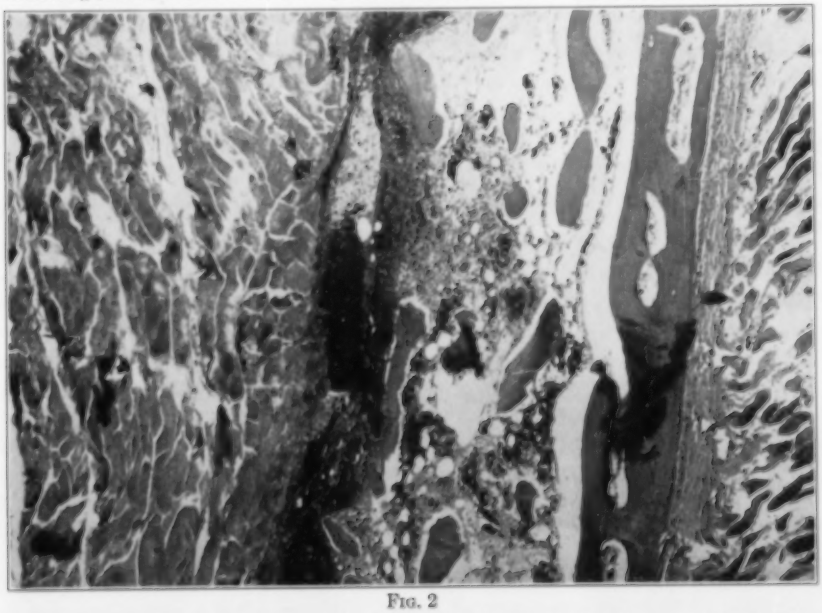

FIG. 2

Photomicrograph of the suction-drained decorticated right iliac crest of the same rabbit at three days showing less hemorrhage and infiltration with closer apposition of muscle to bone (×65).

multiple microscopic sections showed a definite increase in the amount of extravasated blood and tissue reaction; and in those three wounds opened at three, seven, and ten days, more necrosis, fibrosis, and bone production on the undrained side (Figs. 1 and 2).

DISCUSSION

Realizing the frequent association of wound hematomata with postoperative orthopaedic infections, one might logically conclude that the incidence of infection might be decreased by more thorough hemostasis, or, when this is not technically possible, complete drainage of any blood that may accumulate. It is our feeling that catheter drainage of a wound where blood is likely to accumulate most closely approaches this ideal. A silicone rubber catheter was selected for two reasons. It is more inert than ordinary rubber or polyethylene, and, perhaps of more importance, being hydrophobic, blood within the tubing clotted much more slowly [5,9] and did not adhere to the catheter. That clotting within the tube seemed to be a problem was apparent in twelve cases. Perhaps dissolution of these clots with fibrinolysin might be indicated, but this was only attempted and accomplished in one wound of this series [13,17].

TABLE V

CHARACTERISTICS OF COMMON SUCTION SOURCES

Source	Suction (*Millimeters of Mercury*)	Volume (*Milliliters*)
Central suction	Adjustable, constant, 0 → 200	1,400
Gomco machine	Constant, 90 or 120 (closed system)	2,600
Asepto syringe (new)	Constant, 80	50
Disposable pump	Variable, 65 when containing 0 ml.; 40 when containing 100 ml.; 28 when containing 200 ml.; 18 when containing 300 ml.; 10 when containing 400 ml.	400+
Evacuated plasma container	Variable, 740 when containing 0 ml.; 720 when containing 300 ml.; 680 when containing 600 ml.	600+

The 1 per cent infection rate in the wounds treated with suction as compared with the 3 per cent infection rate in the control series is encouraging, but not statistically significant. The association of positive catheter cultures with a generally more febrile postoperative course in the absence of obvious infection suggests that the tissues can combat a certain degree of contamination without development of a frank wound infection.

Experience during routine surgical procedures suggests that suction can perpetuate bleeding. This seems to be confirmed by the animal experiments reported here in which the measured volume of the fluid obtained by suction exceeded the volume of the hematoma found in comparable wounds not drained. The absence of wound-healing problems in the patients treated by suction, however, would seem to indicate that suction drainage by catheter removes blood and serum satisfactorily and furthers the healing process. The loss of an additional 100 to 200 milliliters of blood as the result of suction drainage after a major orthopaedic procedure is a low price to pay for increased assurance of a healthy wound.

The decrease in the packed-cell volume of the drainage fluid collected during the first twelve hours as compared with the packed-cell volume of the fluid collected during the next sixteen hours indicates that active bleeding or oozing usually ceases during the first twelve hours.

Each of the various sources of suction available has advantages and disad-

vantages (Table V). The central suction with adjustable bedside outlets is most flexible. The Gomco machine is simple to use, but with a closed system there is neither interruption nor variation in the negative pressure and an electrical connection is required. A commercially available disposable plastic pump is simple to use, sterile, and conveniently portable [10], but the amount of suction obtained, which depends on the compression characteristics of a spring, decreases markedly as the unit is filled. The evacuated plasma containers developed a level of suction that seemed to be too high.

In most wounds the catheters were retained on suction until there was little drainage, amounting to twenty milliliters or less of serous fluid in eight hours. The time that suction was used averaged thirty-two hours, with a range extending from nineteen to sixty-five hours. Most of the general surgeons who have used this method of drainage for soft-tissue wounds have employed consistently longer periods of suction without ill effect [3,4,11,12,14,15]. However, because of the possible risk of formation of a synovial fistula or retrograde infection, the catheters in this series were usually removed as soon as drainage became scant. In only two instances, as mentioned, did the reaccumulation of a primarily serous fluid suggest that a longer period of drainage might have been desirable.

The motion obtained in hips treated by arthroplasty and suction has been encouraging. For the periods of follow-up involved—from four to thirty-six months—the patients so treated seem to have done better than similar patients at comparable periods after operation who were not treated with suction. It is possible that the effective removal of blood results in the formation of less granulation and scar tissue.

In spine fusions where small chips are placed next to decorticated laminae, the removal of fluid may be beneficial since closer apposition of the bone chips to each other and to the laminae should facilitate revascularization [5]. The removal of a hematoma from the region of an acute fracture would be expected to alter the progression of fracture healing or bone-grafting if the hematoma participates significantly in this process. The role of the hematoma, however, has been questioned and somewhat discredited [6], although this idea has not been universally accepted [16]. In the patients reported here there has been, to date, no demonstrable alteration in fracture healing as the result of the removal of blood and serum, other than a possible reduction in the amount of external callus.

CONCLUSION

Suction drainage, using silicone rubber catheters, is suggested as a method to provide more complete drainage of orthopaedic wounds. A series of 100 cases has been analyzed. It is our impression that wounds involving medullary bone in which complete hemostasis cannot be achieved by ordinary techniques, and wounds in which a potential dead space exists, should have suction drainage. A more benign and uncomplicated postoperative course can be anticipated if this treatment is used.

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DISCUSSION

Dr. Sam W. Banks, Chicago, Illinois: I am a staunch advocate of the effectiveness of closed suction of surgical wounds. I have used suction almost routinely in a manner essentially the same as described by Dr. Waugh and Dr. Stinchfield, employing the disposable hemovac pump and plastic tubes. Approximately 94 per cent of the authors' patients had operations on the hip and spine, but I have used the technique in most of the major joints and various areas of the skeleton. There is no doubt that patients so treated have less pain, the wound shows less swelling, healing of the soft tissues is facilitated, infections are less frequent, and the extremities on which surgery was performed can be mobilized more quickly. The exit of the tubes away from the wound avoids sinus formation and interference with wound healing.

The authors stated in their paper that temperatures were lower after operation when wound drainage was employed. Their statistics, however, do not show a material difference in the mean temperature during the first several days after operation when the control and experimental series are compared. This is a difficult point to prove and although I am inclined to agree with the authors, the final answer must await the accumulation of additional data.

Several disadvantages of this technique have been raised. One is increased blood loss. The amount of bleeding into large wounds and onto dressings following the release of tourniquets is probably comparable in amount to that evacuated from wounds by suction during the first twenty-four to forty-eight hours.

No patient in my experience has required a transfusion in the immediate postoperative period because of blood loss into the plastic pump. Another possible disadvantage is the introduction of infection through the tube system. Dr. Waugh and Dr. Stinchfield found seventeen positive cultures from inside the catheters. The infection rate of wounds was 2 per cent lower than in the control series. Obviously, retrograde infection did not occur. The plastic tubes do become plugged on occasion, and they should be removed rather than irrigated in a retrograde fashion to avoid the introduction of bacteria into the surgical wound. Plugging of tubes can be minimized by washing out all clots from the wound and tube system after the deep layers of the wound have been closed.

May I emphasize that closed wound suction is not wound drainage. Dead spaces with accumulated blood and fluid are more effectively evacuated, as shown by the volume of material obtained from major wounds during the first twenty-four to forty-eight hours after operation, and the tissues are allowed to resume their normal relationship to each other without the interposition of an organizing hematoma.

I highly recommend suction of surgical wounds.

Dr. Harold E. Crowe, Los Angeles, California: For many years I have looked at the postoperative temperature record following large incisions, such as on hips and spines, and have seen the high camel-hump of a temperature rise immediately after operation, which comes down to the normal line and then, on the fourth or fifth day, jumps up again. At this point the surgeon's

(*Continued on page 1021*)

Cuneiform Osteotomy in the Treatment of Slipped Capital Femoral Epiphysis

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ATLANTA, GEORGIA

From the Grady Memorial and Emory University Hospitals, Atlanta, Georgia

This paper is an evaluation of the results of cuneiform osteotomy in the treatment of slipped capital femoral epiphysis at Grady Memorial and Emory University Hospitals during the past twelve years.

Hofmeister and Kocher [13], in 1894, independently suggested the name *epiphyseal coxa vara* for this disease of adolescence. Sprengel, in 1898, described two youths upon whom he had operated, by osteotomy, for pain and increasing disability of the hip. The excised specimen demonstrated what he called an epiphyseal fracture. Whitman, in 1909, advocated the removal of a wedge of bone to effect realignment of the head and neck. In addition to wedge osteotomy as a method of treatment, closed reduction, nailing *in situ*, traction, subtrochanteric osteotomy, and bone-pegging have been practiced [4,6,7,9,11,12,15,17,18].

Although no constant factor has been demonstrated as the cause of slipped capital femoral epiphysis, endocrine and traumatic factors play a significant role. Children with slipped epiphysis are often obese or they have recently undergone a rapid spurt in skeletal growth. Wilson thought that, as the femoral neck inclined toward the horizontal, the epiphysis became more vulnerable. Burrows noted that the disease occurs earlier in girls and is rare in girls who have begun menstruating. After trauma the symptoms are usually mild and are accompanied by varying degrees of pain and lameness. The diagnosis should be suspected in an adolescent who is seen because of hip or knee pain and limp and who, upon examination, is found to have limitation of internal rotation of the hip and to walk with the hip externally rotated. In a majority of patients with slipped capital femoral epiphysis, some degree of shortening of the affected extremity is also noted. The roentgenographic findings, as seen in the anteroposterior and lateral roentgenograms, are widening of the joint space, irregularity and some decalcification in the region of the epiphyseal plate, and relative displacement of the femoral head posterior and inferior to the neck. We would like to re-emphasize the importance of obtaining a lateral roentgenogram of the hip because the slipping sometimes will be missed if only an anteroposterior roentgenogram is made.

MATERIAL

In the past twelve years, nineteen patients with slipped capital femoral epiphysis have had cuneiform osteotomy performed on one of their hips (nineteen hips). Decision to perform osteotomy on all the patients in this group was made by one of us (R.P.K.). The indications for osteotomy were rotation or slipping of the axis of the epiphysis through more than 45 degrees, as seen in either the anteroposterior, the lateral, or both roentgenograms, combined with clinical evidence that this degree of slipping had been present for more than three weeks. The average duration of symptoms was 9.2 months. Roentgenographic findings suggesting damage to the joint surface were accepted as a contra-indication to the procedure. On review of five of our records there is no documentation of the degree of slipping. In the remaining fourteen cases there was roentgenographic

evidence of slipping or rotation of 45 degrees or more. The ages of the patients ranged from eleven to eighteen years with a median age of 14.6 years. Thirteen of the patients were boys. In twelve patients the left hip alone was involved and in three the right; four patients had bilateral disease. The incidence of bilateral involvement in this series corresponds to that reported by Klein and his associates, in which 20 per cent of the cases were bilateral [11,12]. Burrows likewise found that sixty of the 100 patients he studied were boys and that twenty-three had bilateral involvement. Thirteen of our patients gave a definite history of trauma, usually in the nature of a fall; four denied injury, and there was no information on two. Treatment was instituted from one day to three months after onset of pain and limp in six patients; from three to twelve months after onset in six. No information was available on five patients.

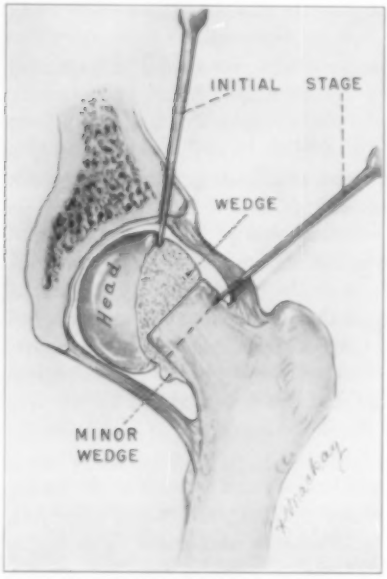

FIG. 1

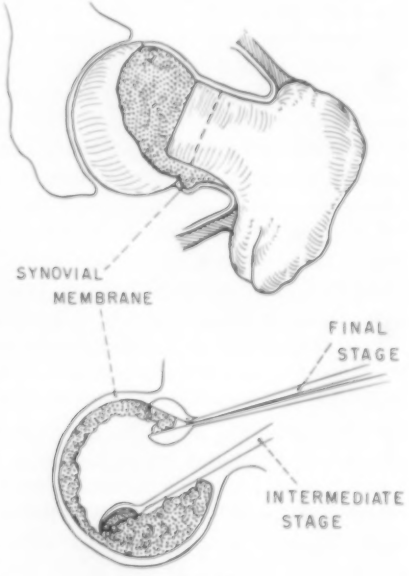

FIG. 2

Fig. 1: Anteroposterior view of the hip showing major anterior superior wedge and minor posterior wedge, as well as the initial stage of the osteotomy.

Fig. 2: View of major and minor wedge when hip is adducted and externally rotated. Cross section of the femoral neck at the osteotomy site demonstrates the intermediate and final stages of the osteotomy.

Before operation eleven patients were treated by either skeletal traction or Buck's extension; six had no specific treatment; and two were immobilized for a period in abduction boots.

OPERATION

A Callahan approach was used. This incision follows the interval between the sartorius and the tensor fasciae latae, beginning proximally at the anterior-superior iliac spine. As the interval is developed distally to the level of the end of the fleshy fibers of the tensor fasciae latae, the incision is curved posteriorly to divide the iliotibial band and the lateral portion of the underlying intermuscular septum. An effort is made to avoid severing the branches of the lateral femoral cutaneous nerve. The reflected head of the rectus femoris is isolated above the rim of the acetabulum and is severed; the muscle is retracted medially. A longi-

tudinal incision is made on the anterior aspect of the capsule to expose the joint. This incision is then converted into a T by making the transverse arm of the T along the proximal attachment of the capsule of the hip at the labrum, carrying the transverse arm as far laterally and medially as possible

The base of the wedge of abnormal bone caused by the slipping is thus exposed. The deep synovial layer is reflected from the femoral neck over the bone to be resected without severing any more synovial tissue than necessary. Cuneiform osteotomy is accomplished with care to preserve the synovial or periosteal covering of the neck (reflected capsule). The head is replaced on the neck and appropriately fixed.

In addition to the obvious anterior superior wedge of abnormal bone formed between the original neck and epiphyseal plate in its displaced position, a wedge of new bone is commonly formed on the posterior aspect of the neck as the posterior edge of the femoral head is displaced posteriorly overriding the proximal portion of the neck. If only the anterior wedge of newly formed bone is removed, the femoral head must be levered over the prominence on the posterior aspect of the femoral neck in order to restore the normal relationship of the head with the anterior aspect of the femoral neck. Tearing of the posterior periosteal or synovial covering of the neck and its accompanying circulatory pathways would seem to be the inevitable result of such a stretching maneuver. For this reason we feel that it is necessary to remove enough of the original substance of the femoral neck to shorten it perhaps two to five millimeters, an amount sufficient to avoid stretching and tearing of these vital structures. This shortening has the additional advantage of permitting ready access to the minor posterior wedge. Once an adequate window has been created in the synovial layer covering the large anterior wedge, much of the bone can be removed by means of a curette. The outer rim of cortical bone of the neck can be removed as necessary with a small ronguer, starting on the anterior aspects of the neck and proceeding superiorly and inferiorly around to the posterior aspect (sometimes a pituitary ronguer will be found useful for this) (Figs. 1 and 2).

When enough bone has been removed to facilitate repositioning of the head on the neck, it is well to skewer the femoral head to the acetabulum with a one-eighth-inch Steinmann pin so placed that it is not in the path of the device to be used for fixation. With the head thus fixed to the acetabulum, the neck is gently manipulated into the desired position and the device for fixation inserted. The transfixing Steinmann pin facilitates the reduction and eliminates risk of twisting the head and thus wringing out its blood supply during the manipulation or the insertion of a screw or a pin. Because of its lag-screw effect a wood screw is a satisfactory device for fixation and snug approximation of the head to the femoral neck (Fig. 5). Obviously the wood screw must be long enough to gain a firm bite in the femoral head so that its lag-screw action can operate effectively but short enough not to penetrate the articular surface when it is tightened. When the screw has been inserted and its position demonstrated to be satisfactory by anteroposterior and lateral roentgenograms, the transfixing Steinmann pin is removed. The capsule and wound are then closed.

The blood supply to the femoral head was evaluated in fourteen of our patients at the time of surgery. In nine hips there was active bleeding from the cut surface of the femoral head; in five there was no active bleeding. No information was given in the operative notes of five patients. In ten patients a wood screw was used, and in seven a Lloyd-Collison lag screw was used for fixation. In one of the remaining two, a Smith-Petersen nail was used for fixation, and in the other, two Knowles pins. After operation thirteen patients were maintained

with their hips in abduction and internal rotation by plaster boots attached to a cross-bar; five were maintained in Russell's traction, and one was immobilized in a hip spica. The duration of immobilization ranged from one week to sixteen weeks. All patients were allowed to walk with crutches and partial weight-bearing at the end of the period of immobilization. The time of full weight-bearing was determined by roentgenographic evidence of healing of the osteotomy site. None of our patients was allowed full weight-bearing until three months after surgery; six were permitted full weight-bearing at from three to six months after operation; only one was not allowed full weight-bearing at the end of one year. This patient later had a subtrochanteric osteotomy for non-union of the osteotomy of the femoral neck. In Figure 3 the results are correlated with the time between operation and the resumption of full weight-bearing.

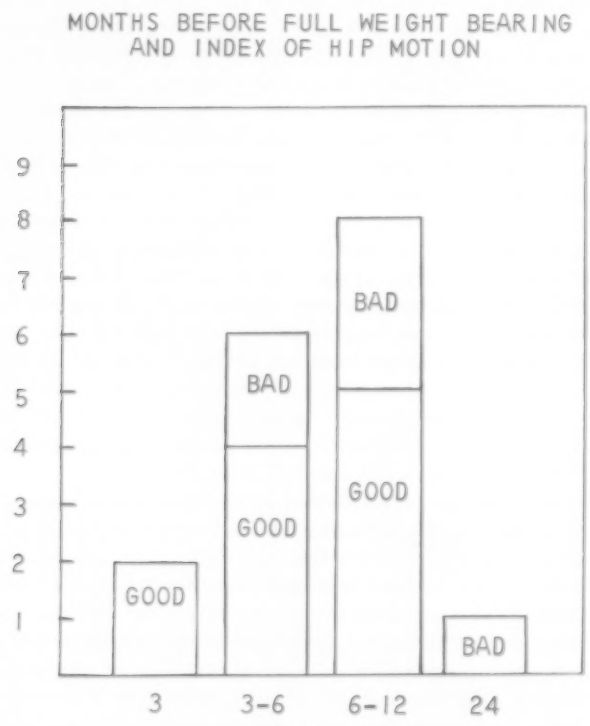

FIG. 3

Relation of the time before full weight-bearing was started and the index of hip function.

RESULTS

In order to set up criteria for the evaluation of our results we adapted the index of function described by Ferguson and Howorth; and at the same time took into consideration alteration in gait, roentgenographic changes, and the presence or absence of pain. The index of hip motion was determined by multiplying each range of hip motion by a designated factor. The sum of these products was the index of hip function—a numerical value on which basis a hip may be graded as normal, good, fair, poor, or bad (Table I). Using the other criteria (gait, roentgenographic changes, and pain) the results were rated as follows:

With a normal result the patient had no symptoms whatsoever and no roentgenographic changes.

With a good result the patient might have mild discomfort at the end of the day or a slight limp but no roentgenographic changes.

With a fair result the patient had mild symptoms, pain or limp, and early degenerative changes as seen by roentgenogram.

With a poor or bad result the patient had moderate or severe limp, more or less constant pain on activity, and aseptic necrosis, degenerative changes, or varus deformity of the femoral neck as shown by roentgenogram.

We were able to study the results in seventeen of the nineteen patients who were followed for from one and one-half to twelve years. Four were followed for twelve years, five for six years, and four for one and one-half years. The four remaining patients were followed for two, three, four, and five years, respectively. Two patients were lost to follow-up and were dropped from this study.

TABLE I

INDEX OF HIP FUNCTION *

	Normal Motion	Factor	Product
Flexion	140	0.4	58
Abduction	45	0.4	18
Adduction	10	0.2	2
Internal rotation	45	0.2	9
External rotation	60	0.1	6
Extension	10	0.1	1
		Total	94

MULTIPLY THE MEASURED RANGE OF MOTION BY THE FACTOR AND THEN ADD THE PRODUCTS

RESULTS

Normal	90 to 110	Poor	30 to 50
Good	60 to 90	Bad	Less than 30
Fair	50 to 60		

* Index of Hip Function adapted from "Slipping of the Upper Femoral Epiphysis: A Study of Seventy Cases" by A.B. Ferguson and M. B. Howorth. J. Am. Med. Assn., **97**: 1867–1872, 1931.

In two of the nine patients in whom there was evidence of blood supply to the femoral head at the time of surgery, aseptic necrosis subsequently developed. Two other patients showed evidence of aseptic necrosis; one of these patients was from the group of five who showed no evidence of bleeding from the cut surface of the femoral head at the time of surgery; the other was one of the patients whose record had no note as to the apparent vascularity of the femoral head at operation. Aseptic necrosis was evident by roentgenogram in two patients six months after surgery and in the other two at the end of one year. The one hip with degenerative changes first showed these on a roentgenogram made two years after operation. No additional cases of aseptic necrosis were observed after one year.

We were struck by the close correlation between the index of hip function of our patients with the other findings (alteration in gait, roentgenographic changes in the hip, and pain). The index of hip function was normal (90 to 110) in six, good (60 to 90) in five, poor (30 to 50) in three, and bad (0 to 30) in three. In the overall evaluation of the results, there were ten patients (59 per cent) with good to normal results, one with a fair result, and six (35 per cent) with poor results.

One patient with a good index of hip motion was rated as a fair result because the index was just barely within the good range and the patient had pain and early degenerative changes as shown by roentgenogram.

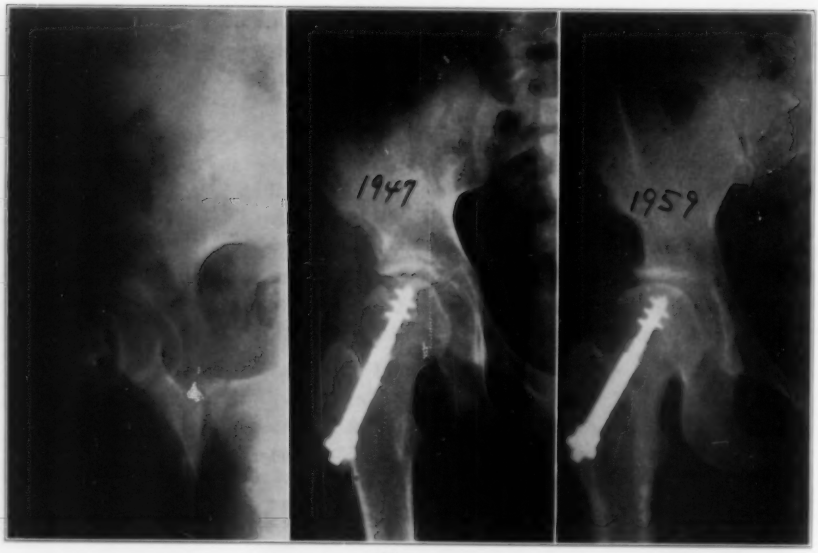

FIG. 4

G.W.W., a twelve-year-old Caucasian girl, has no pain and no limp twelve years after operation. Index of hip motion is 93.

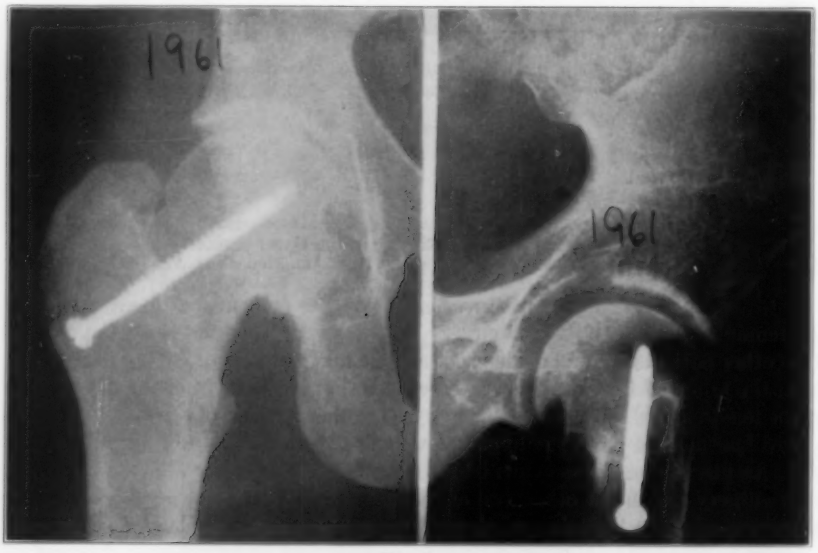

FIG. 5

C.L., a fourteen-year-old Negro boy, has no pain and no limp six years after operation. Initial roentgenograms are not available. Index of hip motion is 92.

Of the remaining ten patients with a good or normal index, only one complained of any discomfort. This was mild aching noted in the late afternoon. Two more of these ten patients had a slight limp but no pain, a normal roentgenogram, and a normal index of hip motion.

All patients with a poor or bad index of hip motion had a limp that ranged from moderate to severe as well as pain. Four had aseptic necrosis; one had de-

FIG. 6

R.P., a fifteen-year-old Caucasian boy, had non-union treated by subtrochanteric osteotomy without bone-grafting. Five years after operation he had no pain and no limp. Index of hip motion is 79.

generative changes of the acetabulum, the femoral head being apparently normal; and another had a varus deformity of the femoral neck.

Cleveland and his associates, in 1951, reported fourteen patients with severe displacement who were treated by wedge osteotomy, with good results in twelve. Martin, in 1948, reported on seven patients with an average follow-up of twenty-one months; in these there were six excellent results and one poor result which he attributed to faulty technique. Badgley and his associates said that with careful selection of the cases and proper operative approach the transcervical osteotomy with adequate fixation gave the best chance for a good functional hip. He reported 56 per cent excellent results and 9 per cent good results.

Fibrous ankylosis of the hip developed in one of our four patients with aseptic necrosis. In two others, the screw penetrated the femoral head, and second procedures were necessary to replace the screws. Despite this complication, one of these two patients had a good end result; the other, unfortunately, was lost to follow-up. There were two patients who had non-union, caused by a too vertical plane of the osteotomy. In both patients a secondary subtrochanteric osteotomy was performed after removal of the screw, and both osteotomies were fixed with a blade plate. Bone grafts were not used. In one the end result is known to be good (Fig. 4); the other was lost to follow-up.

The use of wedge osteotomy for late correction of marked slipping of the capital femoral epiphysis has been described many times [1,4,6,7,10,11,12,18]. The need for meticulous surgery and preservation of the blood vessels along the inferior portion of the neck has been emphasized in practically all discussions. A point which we feel is important in the preservation of vascular integrity is the removal of an adequate wedge of bone by careful dissection so that the neck can be brought into proper alignment with the head, which is fixed temporarily by a small Steinmann pin transfixing it and the acetabulum. By this maneuver undue tension on the synovial membrane of the postero-inferior aspect of the femoral neck is avoided. Compere emphasized the importance of placing the osteotomy in such a plane that the weight-bearing force is horizontal rather than vertical. We found that failure to achieve this plane resulted in non-union in two of our patients. Key and Badgley and his associates noted that a subtrochanteric osteotomy does not correct the primary pathological change and offers only temporary relief.

SUMMARY

This study of wedge osteotomy in the treatment of marked slipping of the capital femoral epiphysis, with a follow-up of from one and a half to twelve years

(average, 5.8 years), evaluates index of hip function, roentgenographic changes, gait, and history of pain. Good results are dependent upon good exposure, extreme care in preservation of the blood supply to the femoral head, adequate wedge resection of the femoral neck, effecting a valgus position of the epiphysis at surgery, proper placement of the plane of osteotomy, and adequate internal fixation supplemented by external fixation when necessary.

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Avascular Necrosis of the Skin after Operations on the Foot*

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Stimulated by the relatively frequent occurrence of necrosis of the skin after operations on the foot, we have studied the superficial vascular bed in the areas of incisions made for triple arthrodesis, lengthening of the heel cord, translocation of the peroneus longus tendon, and stripping of the plantar fascia. Twenty-one lower extremities, which had been amputated because of malignant tumors, were used for this study. The processing of each specimen was started within a half hour after amputation. Fourteen specimens were injected with a colloidal suspension of barium sulphate and were cleared *in toto* by means of the Spalteholz [6] technique: these specimens demonstrated the gross pattern of the superficial vessels. Two other injected specimens were dissected to confirm the impressions gained from the cleared feet. The remaining five feet were injected with India ink and gelatin, were cleared *in toto*, and were cut into multiple sections for microscopic examination. Details of this entire study, which form the basis of our observations presented in this paper, are published elsewhere [3].

TRIPLE ARTHRODESIS

Necrosis of the skin on one side or both sides of the incision for triple arthrodesis is not uncommon. It rarely results in complete dehiscence of the wound with exposure of deeper structures and subsequent infection, but it is an annoyance to the patient because it delays the healing of wounds.

Our specimens showed that the skin in the area of the conventional approaches to the tarsal bones is supplied mainly by the perforating branch of the peroneal artery, by the lateral tarsal artery, and, to a minor degree, by the dorsalis pedis artery.

The perforating branch of the peroneal artery emerges at the distal end of the interosseous space between the tibia and the fibula, crosses the lateral portion of the ankle joint, and runs deep and proximal to the origin of the extensor digitorum brevis muscle, closely hugging the inferolateral portion of the talus. It then turns gently to continue along the lateral margin of the extensor digitorum brevis muscle, eventually anastomosing with one of the terminal branches of the lateral tarsal artery. This vessel furnishes most of the cutaneous vessels in the area over the sinus tarsi. The cutaneous vessels traverse a pad of fat overlying the opening of the sinus tarsi.

The lateral tarsal artery runs in an obliquely distal direction under the extensor digitorum brevis muscle. One of the main terminal branches of the lateral tarsal artery turns back to anastomose with the perforating branch of the peroneal artery.

It is characteristic that almost no cutaneous arteries run through the substance of the extensor digitorum brevis; however, an isolated small vessel may

* Abridgement of thesis submitted by Dr. Pyka to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science in Orthopedic Surgery.

emerge from between two digits of the muscle. The skin covering the extensor digitorum brevis has the poorest blood supply in the foot. Grossly, only a few thin and long arteries feed it. Coming from deeper vessels at the sides of this muscle, they circle it, form a few anastomoses, and exhaust themselves (Fig. 1). Laterally, they come from the perforating branch of the peroneal artery; medially, they come from the dorsalis pedis or the lateral tarsal artery. The vessels form a wide-meshed network, with each artery supplying a relatively large area.

The dorsalis pedis artery extends between the extensor hallucis longus and extensor digitorum longus tendons. The cutaneous branches of the dorsalis pedis artery aid in the supply of the skin over the neck of the talus.

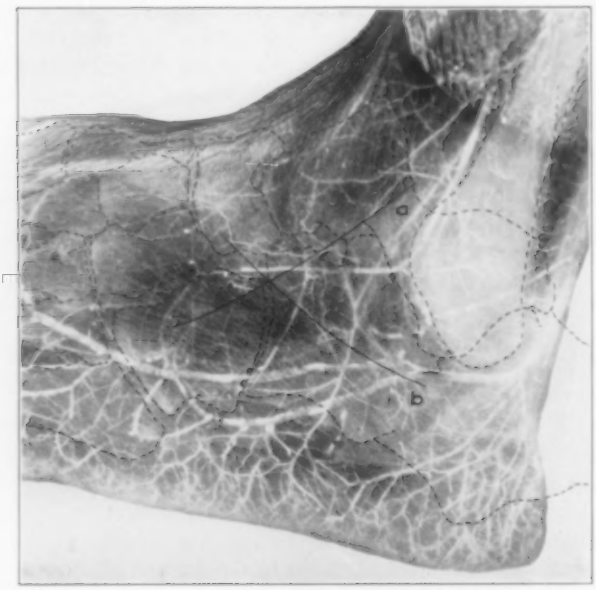

FIG. 1

Lateral view of injected foot and ankle, with vessels filled with a colloidal suspension of barium sulphate and bones superimposed. Note the path of the anterolateral incision (*a*) and the oblique tarsal incision (*b*).

The microscopic vascular pattern on the dorsum of the foot is not dense (Figs. 2-A through 2-D). It is dissimilar to the pattern in the plantar skin for which Spalteholz [4,6] determined a cutaneous and subpapillary arterial plexus and four different venous plexuses extending parallel to the surface. We are not certain whether the vessels in and under the dorsal skin deserve the name *plexus* at all. They branch and anastomose as vessels would on any surface. The ascending arteries within the skin ramify like branches of a tree. As they approach the surface, they assume an oblique and even horizontal course. Although anastomosing, they remain distinctly individual. This is in contrast to the microscopic vascular pattern of the plantar skin in which the branches form dense anastomotic networks. The dermal cones on the dorsum of the foot are irregularly distributed.

Two incisions are commonly used for triple arthrodesis [1,2] (Fig. 1):

1. The anterolateral incision starts medial to the lateral malleolus and extends straight or slightly curved beyond the superior margin of the calcaneocuboid joint.

2. The oblique tarsal incision extends along the sinus tarsi between the

peroneal and extensor digitorum longus tendons. If necessary, this incision can be extended underneath and behind the lateral malleolus; it then becomes the Kocher incision.

Avascular necrosis may develop after both of these incisions, particularly after the extensive Kocher approach. In the process of excavating the sinus tarsi, the surgeon may excise in one piece, with the interosseous talocalcaneal ligaments, the fat pad which carries the delicate cutaneous branches of the perforating branch

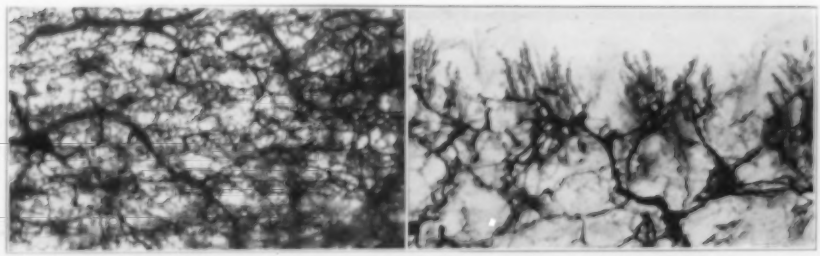

FIG. 2-A FIG. 2-B

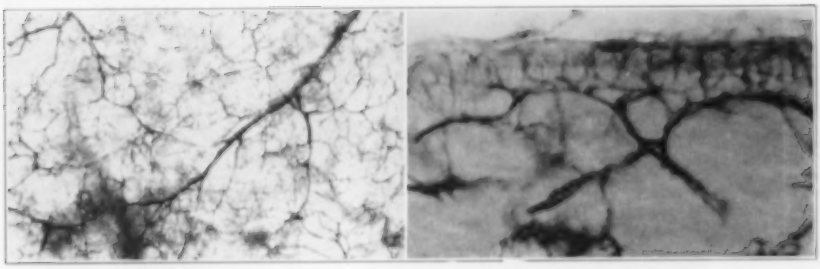

FIG. 2-C FIG. 2-D

Figs. 2-A, 2-B, 2-C, and 2-D: Comparison between the vascular network of the plantar (Figs. 2-A and 2-B) and the dorsal (Figs. 2-C and 2-D) skin (India ink and gelatin preparations).

Fig. 2-A: Surface view (×9). Dermal ridges with a fine vascular network composed of rather rectangular, parallel meshes constitute the first venous plexus. The papillary vessels are just visible at this magnification. They are arranged in double rows. Note also the fine, irregular arteries of the subpapillary plexus and the heavier veins located deeper in the skin.

Fig. 2-B: Cross section (perpendicular to dermal ridges, ×30). The superficial portion of the corium is more vascular than the deep one. The papillary vessels are arranged in groups, each group representing one dermal ridge. The principal vessels deeper in the corium are called *candelabrum arteries* because their branches resemble the arms of a chandelier.

Fig. 2-C: Surface view (×9). Irregular distribution of vessels in the skin of the dorsum of the foot. The ascending branches divide like branches of a tree. Although anastomosing, they remain distinctly individual. The vessels are not so dense as are those in the plantar skin.

Fig. 2-D: Cross section (×30). In this type of skin there are also candelabrum arteries and papillary loops. There is no specific grouping: the number of vessels as compared to that in Fig. 2-B is markedly reduced.

of the peroneal artery. This action seriously impairs the local blood supply. The distal portion of the customary incisions extends over the extensor digitorum brevis muscle, the belly of which is detached proximally and reflected distally. No matter how carefully this is done, many of the cutaneous branches of the lateral tarsal and anterior peroneal arteries, which encircle the margins of the short toe extensor, will be severed or at least damaged during exposure. For healing of the wound, the skin must then depend upon the blood supply from more remote areas.

The major cutaneous arteries tend to run in a longitudinal direction. An oblique tarsal incision crosses more of them than does an anterolateral incision.

Theoretically, therefore, the incidence of circulatory complications of the skin referable to an incision should be higher after the oblique tarsal incision is used than after the anterolateral approach to the tarsal bones is employed. It was not possible, however, to compile any material of statistical significance to substantiate this impression.

LENGTHENING OF THE HEEL CORD

Delayed healing of the wound may take place after lengthening of the heel cord. The Achilles tendon usually is approached through a posteromedial incision.

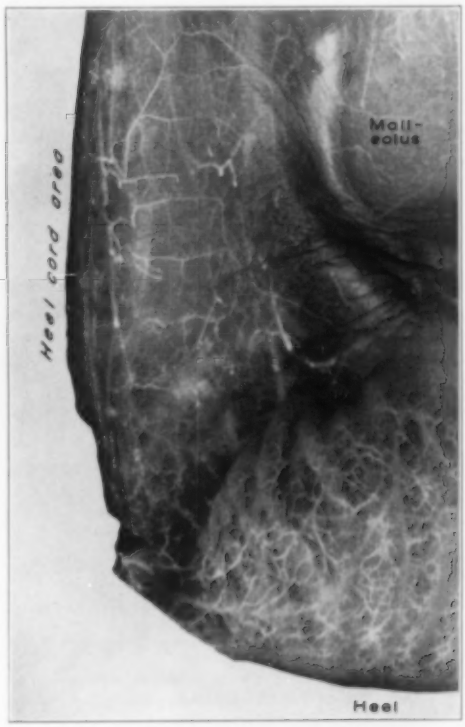

FIG. 3

FIG. 4

Fig. 3: Loose plexus of arteries in the skin overlying the heel cord (posterior view). No cutaneous arteries traverse the heel cord itself.

Fig. 4: Thick coronal section through the hind part of the foot. The section goes through the distal end of the fibula and through the lateral portion of the calcaneus. The right, vertical margin of the specimen is formed by skin. Note that the principal vessels supplying this area (rami calcanei laterales) run very close to bone. The cutaneous arteries arrive at the surface after a rather long, oblique course through subcutaneous tissue.

Our specimens revealed that the skin over the heel cord is supplied by a loose plexus of thin arteries which receive blood on one side from the posterior tibial artery and, on the other, from the rami calcanei laterales, the terminal branches of the peroneal artery. No cutaneous arteries traverse the heel cord itself (Fig. 3).

When the skin is cut through on the medial side of the heel cord, one side of the incision will have to depend upon blood coming from the terminal portion of the peroneal artery at some distance away. However, the skin overlying the Achilles tendon is very thin, and beneath it the subcutaneous tissue is sparse, so that there is little tissue which would provide space for a tridimensional

anastomotic network. Microscopically, the vessels form a pattern comparable to the one encountered on the dorsum of the fore part of the foot. In some patients the vascularity of this area is apparently not sufficient to provide enough blood for adequate healing of wounds, especially if the skin becomes stretched as the ankle is brought to a right angle and is immobilized in this position.

TRANSLOCATION OF THE PERONEUS LONGUS TENDON

This operation is done through two incisions: the first extends along the peroneal tendons and the second is made along the apex of the heel. The soft tissue between both incisions is supplied by the rami calcanei laterales. These vessels run very close to the lateral aspect of the calcaneus. The branches are

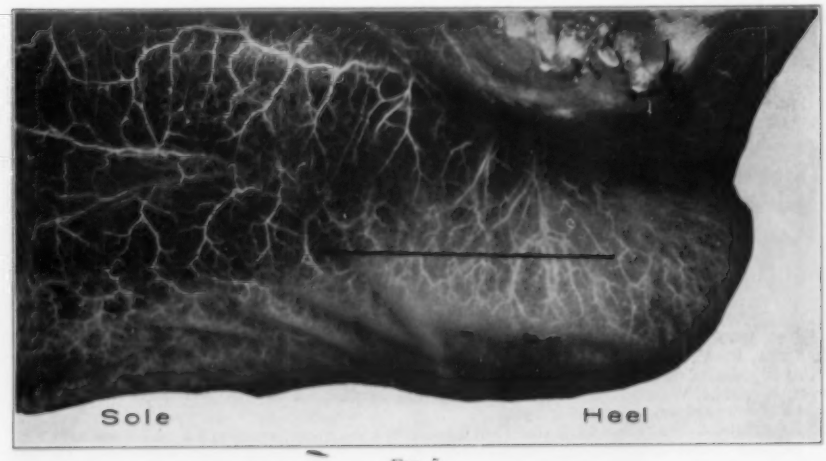

FIG. 5

Surface view of the medial aspect of the heel. The cutaneous arteries descend vertically down to the sole. An incision for stripping of plantar fascia crosses them all.

relatively extensive, and they arrive at the surface only after a rather long oblique course through the subcutaneous tissue (Fig. 4). When the operation of rerouting the tendon of the peroneus longus is done, the surgeon may find himself greatly attracted to the maneuver of pulling the tendon back toward the heel through subcutaneous tissue. However, this action inevitably severs the rami calcanei laterales. To preserve the blood supply of the skin, the flap should be lifted only after subperiosteal dissection of the flap has been done. For practical purposes, the rami calcanei laterales should be considered to be lying on bone.

STRIPPING OF THE PLANTAR FASCIA

Hematoma and delayed healing of wounds after stripping of the plantar fascia are not infrequent. The posterior tibial artery gives off multiple branches which convey blood to the weight-bearing area of the heel. They branch off the main vessel more or less perpendicularly. The incision used for release of the plantar fascia crosses these branches at a right angle (Fig. 5).

COMMENT

We realize that severance of cutaneous vessels can be only one of the factors leading to necrosis of the skin after a surgical incision. Mechanical trauma at the time of operation, tight closure of the skin, tight dressings, and pressure from a

cast also play a role. Avoidance of mechanical trauma is of particular importance in the case of operations in the area of the sinus tarsi.

The skin covering the dorsum of the foot is thin and has very little subcutaneous fat. There is no dense cutaneous vascular plexus which provides abundant quantities of blood for rapid repair of tissues. Therefore, the skin on the dorsum of the foot can tolerate little trauma. While performing triple arthrodesis, the surgeon works in the depth of the wound. During the process of resecting or curetting the joint surfaces, the skin may become severely crushed if it is caught between the instrument and bone; this may also occur if retraction is faulty.

In order to minimize surgical trauma to the skin, flaps should be kept as thick as possible and care should be taken that no instrument used in the depth of the wound presses firmly against the skin.

SUMMARY

The cutaneous vascular supply of twenty-one feet of extremities amputated for malignant tumors was studied in relation to necrosis of the skin occurring after triple arthrodesis, heel-cord lengthening, translocation of the peroneus longus tendon, and stripping of plantar fascia. Additional factors responsible for delayed healing of wounds are discussed.

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A Roentgenographic Study of the Development of the Calcaneus by Means of the Posterior Tangential View

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This is a roentgenographic study of the development of the posterior portion of the foot, using, primarily, a posterior tangential view. The posterior tangential view is made while the subject stands on a cassette with both feet parallel. The x-ray tube is placed thirty-six inches behind the target and is directed anteriorly and inferiorly toward the malleoli at an angle of 45 degrees with the long axis of the lower extremities (Fig. 1). Infants and very young children are supported in

FIG. 1

Photograph showing the technique for making the posterior tangential roentgenogram. The patient stands on a cassette on the platform of the upright tilt table. The central roentgen ray is aimed at the level of the tips of the malleoli at an angle of 45 degrees to the long axis of the lower extremities.

the standing position by a parent with the feet placed symmetrically on the cassette in the plantigrade position to simulate weight-bearing. It may be difficult to achieve this position; it requires a great deal of patience on the part of the technician to make certain that the feet are properly placed.

Similar roentgenographic techniques have been previously described. Harris and Beath [3,4] used a comparable technique for the demonstration of a talocalcaneal bar. In their procedure, the tube and cassette are similarly placed but the subject flexes the knee to dorsiflex the foot. Early in our study, we followed this technique but found that dorsiflexion did not improve visualization of the subtalar joint. Another technique, the so-called suroplantar view, described by Kandel, provides similar information. With the usual tangential view used for fractures of the calcaneus, the x-ray tube is directed perpendicular to the cassette without dorsiflexion of the foot. By this technique the posterior portion of the body of the calcaneus is visualized, but not the subtalar joint or the sustentaculum

FIG. 2-A

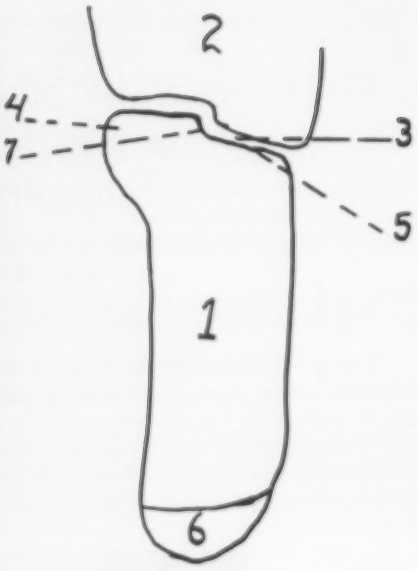

FIG. 2-B

Fig. 2-A: Posterior tangential roentgenogram of a neutral foot of a child, eleven years old.
Fig. 2-B: A drawing of the roentgenogram shows the calcaneus, 1; the talus, 2; the subtalar joint, 3; the sustentaculum tali, 4; the posterior articular facet of the calcaneus, 5; the epiphysis of the calcaneus, 6; and the step between the posterior articular facet and the sustentaculum tali, 7.

tali. The posterior tangential view, as described in the beginning of this article, provides a roentgenogram that shows clearly the posterior portions of the calcaneus, the subtalar joint, and the sustentaculum tali (Figs. 2-A and 2-B).

Gardner, Gray, and O'Rahilly demonstrated that the bones of the feet are fully formed in cartilage and have assumed contours that approximate those of the adult between the fifth and seventh weeks of fetal life. In approximately the third month of fetal life, ossification starts in the calcaneus and, shortly thereafter, in the talus [1,2,6]. At birth, the calcaneal ossification center appears as an oval area of increased density in the hind portion of the foot, and the talar ossification center appears as a more circular structure just above it. In anatomical dissections, Kandel demonstrated that the ossification centers of the talus and calcaneus in both normal feet and club feet of stillborn infants are centrally located in the transverse and longitudinal planes of the cartilage mass of each bone. In view of this, it can be assumed that the ossification centers, as seen on the roentgenograms, indicate the anatomical relationship of these bones.

At birth, the relationship between the ossification centers of the calcaneus and talus will differ, depending on whether there is a clinically normal foot, a club foot, or a flat foot. Thus, the posterior tangential roentgenogram will show whether the heel is in mid-position, in inversion, or in eversion. If this view is made with the patient standing naturally and with reasonable care that the feet are similarly placed on the cassette, then the roentgenogram provides a true picture of the relative positions of the talus and calcaneus. In the adult foot, we have not been able to demonstrate any change in the relative positions of the talus and calcaneus during inversion and eversion by this view, even in an amputated limb with a Steinmann pin inserted in the calcaneus as a lever. However, if stress is applied to the foot of a young child, either in inversion or eversion, there may be sufficient ligamentous relaxation to allow the change in the relationship between the talus and calcaneus to be visible on roentgenograms made with this

FIG. 3

FIG. 4

Fig. 3: Posterior tangential roentgenogram of a neutral foot of a child, two weeks old. The egg-shaped, ossified portion of the calcaneus lies lateral to the round ossified nucleus of the talus. The calcaneus does not appear to support the talus.

Fig. 4: Posterior tangential roentgenogram of a neutral foot of a child, six months old. The shadow of the calcaneus now shows the posterior articular facet, 1; the developing medial concavity below the sustentaculum tali, 2; and the prominence indicating beginning ossification of the sustentaculum tali, 3.

projection. At birth, the shape of the ossification centers of the calcaneus and talus is the same in apparently normal feet, club feet, and flat feet. As these bones grow, adaptive changes appear which depend on the spatial relationships between the bones. When these adaptations have fully developed, the shape of the bones remains constant and cannot be altered by any change in the position of the foot. However, if a club foot is truly corrected at or shortly after birth, the change in relationship between the talus and calcaneus is reflected on the roentgenogram (Figs. 9-A and 9-B).

Certain changes, which cannot be clearly visualized on conventional roentgenograms of the feet, particularly if the roentgenograms are made without weight-bearing, may be evident on the posterior tangential view. This view of the calcaneus and talus clearly differentiates between an anatomical arrangement that is within normal limits and the anatomical arrangement in a club foot (congenital talipes equinovarus) or in a flat foot (pes planovalgus). Needless to say, this view only reveals the contours and relationships of these two bones; no attempt is being made at this time to establish the relationship of the observed changes to function of the foot or to symptoms.

In this study, the feet of 102 children were investigated, twenty-nine with

TABLE I *

Age	Neutral	Flat Foot	Club Foot
Under 1 yr.	2	6	2
1 yr.	1	10	1
2 yrs.	1	5	1
3 yrs.	2	1	0
4 yrs.	1	8	1
5 yrs.	1	4	1
6 yrs.	0	2	3
7 yrs.	1	0	5
8 yrs.	2	1	1
9 yrs.	3	4	0
10 yrs.	3	4	2
11 yrs.	4	1	0
12 yrs.	1	2	5
13 yrs.	2	2	2
14 yrs.	2	1	1
15 yrs.	2	0	0
16 yrs.	1	0	0
17 yrs.	0	0	1
	29	51	26 in 22 patients

* The club-foot figures indicate twenty-six roentgen series in twenty-two patients because four patients had two examinations at different ages, one at seven and eight years of age, two at ten and twelve years of age, and one at twelve and thirteen and a half years of age.

normal feet, fifty-one with flat feet, and twenty-two with club feet (Table I). All the deformities were congenital. The investigations included a clinical evaluation and a posterior tangential roentgenogram, as well as anteroposterior, lateral, and dorsiplantar roentgenograms made with the children standing.

Because of the wide variation in feet that are usually considered to be normal we have classified the feet in this study in three categories. Although we are not prepared, as yet, to present clear-cut definitions of these three types of feet, the following descriptions are given for purposes of this discussion.

Neutral feet were those feet considered anatomically to be within normal limits. We use the word *neutral* in preference to *normal* because the information obtained from these roentgenographic studies was not sufficient to classify a foot as normal in every respect. The word *neutral* which, by definition, means in the middle position between extremes seems to convey the true significance of the findings in the normal feet in this study rather than the word *normal*.

The feet classified as neutral were plantigrade with sufficient dorsiflexion of the calcaneus to provide a definite longitudinal arch. In all the roentgenographic views the bones were symmetrical and there was no angulation, widening, or narrowing of any of the joint spaces. The longitudinal axis of the talus in the dorsiplantar view was in line with the long axis of the first metatarsal; and, in the anteroposterior view of the ankle, the fibula appeared to be well seated within the groove on the lateral aspect of the tibia.

Flat feet were also plantigrade but the calcaneus was not dorsiflexed and the longitudinal arch was low. The calcaneus was everted with the tuberosity directed laterally in the posterior tangential view. In the dorsiplantar view, the head and neck of the talus were directed medially and the navicular and fore part of the foot were abducted. As a result, the head of the talus was unduly prominent on the medial aspect of the foot. In the dorsiplantar view the longitudinal axis of the talus, when projected distally, lay medial to the long axis of the first metatarsal. In the anteroposterior view of the ankle, the mortise was rotated medially, the fibula often appeared to be out of the groove on the lateral aspect of the tibia, and the interval between the two bones was widened.

FIG. 5

FIG. 6

Fig. 5: Posterior tangential roentgenogram of a neutral foot of a child, fifteen months old. The calcaneus has elongated; the posterior facet and the sustentaculum tali are more ossified and better defined. The talus now appears to be better supported by the calcaneus.

Fig. 6: Posterior tangential roentgenogram of the neutral foot of a child, four years old. Early evidence of the step between the posterior articular facet and the sustentaculum tali is visible. Compare with Figs. 7 and 10.

Club feet appeared to show greater variation, which was thought to be the result of treatment. All club feet showed restriction of dorsiflexion, some sufficient to prevent the foot from assuming the plantigrade position. The calcaneus was inverted under the talus in the posterior tangential view. In the dorsiplantar view, the head of the talus was prominent on the lateral aspect of the ankle and the navicular and cuboid were shifted medially, whereas the fore part of the foot was plantar flexed and adducted. This malposition caused the distal projection of the longitudinal axis of the talus to lie lateral to the first metatarsal. In the anteroposterior view of the ankle the mortise was rotated laterally, and the fibula lay behind the tibia and was overlapped by it to a greater or lesser degree.

RESULTS

Neutral Feet

Twenty-nine children from two weeks to sixteen years of age had neutral feet. At two weeks, the ossification center of the calcaneus is an elongated, almost egg-shaped bone which lies on the fibular side of the posterior portion of the foot. The ossification center of the talus appears as a rounded bone lying anterior and superior to the calcaneus on the tibial side of the foot. At this stage none of the bone structure of the calcaneus extends medially under the talus. Although the cartilaginous precursor of the sustentaculum tali has already formed, it is not visible roentgenographically and there is no apparent bone support for the talus (Fig. 3). At six months, the ossification center of the calcaneus has become longer

FIG. 7

FIG. 8

Fig. 7: Posterior tangential roentgenogram of a flat foot (pes planovalgus) of a child, three and one-half years old. The sustentaculum tali is poorly defined, and the posterior articular facet of the calcaneus inclines medially. The talus does not appear to be well supported by the calcaneus. Compare with Figs. 6 and 10.

Fig. 8: Posterior tangential roentgenogram of a flat foot of a child, ten years old. The articular surface of the sustentaculum tali and the posterior articular facet are nearly parallel and both incline medially. The step between the two articular surfaces is very low.

and cigar-shaped, and a concavity on its medial margin has begun to appear. The transverse line of increased density indicating the location of the posterior facet of the calcaneus in the subtalar joint can be identified. The ossified portion of the talus still appears to be unsupported by the ossified portion of the calcaneus (Fig. 4). By fifteen months, the shape of the calcaneal ossification center is roughly rectangular, and there is a well marked medial concavity. The prominence of the sustentaculum tali is beginning to show on the medial border. About one-fourth of the talus now appears to rest on the ossified portion of the calcaneus (Fig. 5). As the child grows, the sustentaculum tali becomes more prominent, and there appears to be more support offered to the talus by the calcaneus. At two years of age, approximately one-third, and by three years of age, approximately one-half of the talus is supported. At four years of age, the calcaneus has become definitely rectangular in shape. The posterior facet of the subtalar joint can now be seen clearly as a transverse line on the dorsum of the calcaneus, and the sustentaculum tali is well developed and elevated, like a step on a flight of stairs, above the level of the posterior facet of the subtalar joint. The posterior tubercle of the calcaneus has become roughened and a small epiphysis is visible at this site. At this time there appears to be still greater support supplied for the talus by the calcaneus (Fig. 6). At five years of age, a large posterior epiphysis is visible, and the bone has an almost adult configuration. The entire ossified portion of the talus

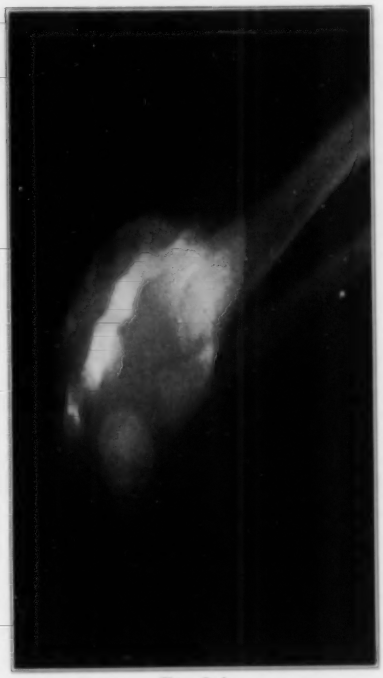

FIG. 9-A

FIG. 9-B

Fig. 9-A: Posterior tangential view of an untreated club foot of a child, two weeks old. The shadows of the talus and calcaneus are superimposed owing to the inverted position of the calcaneus. A double shadow is evident to close inspection. Compare with Fig. 3.

Fig. 9-B: Same foot four months later after correction by changes of plaster. The calcaneus is now lateral to the talus which can clearly be seen superiorly and medially.

now appears to be supported by the calcaneus. This relationship continues into adult life, except that at about fourteen years of age the calcaneal epiphysis fuses to the body of the calcaneus (Fig. 2-A).

Flat Feet

Fifty-one children with flat feet were examined. Their ages ranged from three months to fourteen years. The configurations of the centers of ossification of the talus and calcaneus developed very much like those in the neutral feet. The calcaneus was first ovoid, then cigar-shaped, and later rectangular. However, some consistent variations from the neutral were noted. The posterior facet of the calcaneus in the subtalar joint was identified at one year, but, instead of lying in the horizontal plane, it was inclined so that it was higher on the lateral than on the medial side of the foot. The sustentaculum tali appeared shortly after twelve months but its articular surface was at or below the level of the posterior facet of the subtalar joint, with the result that it did not form a definite step. Apparent support of the ossified parts of the talus by the corresponding portion of the calcaneus appeared late, developed more slowly, and was not complete until the age of fourteen years. The roentgenographic appearance of the talus and calcaneus in the flat foot suggests that the talus is resting on an inclined plane (Figs. 7 and 8).

Club Feet

Twenty-two children had club feet. Their ages ranged from seventeen days

FIG. 10

Posterior tangential view of a corrected club foot of a child, four years old. The short, hypoplastic calcaneus curves medially near its tuberosity. The articular surface of the sustentaculum tali slopes medially and the posterior articular facet slopes laterally. The step between the posterior facet and sustentaculum tali is prominent. Compare with Figs. 6 and 7.

to seventeen years. One child at two weeks had no treatment; and, in this infant's club foot, the calcaneus was inverted under the talus on the tibial side of the foot away from the usual position of the talus on the fibular side (Fig. 9-A). In all the other children who had treatment the calcaneus was inverted under the talus and appeared shorter than in the neutral feet of comparable age. This shortening is, in part, the result of hypoplasia and, in part, the result of apparent shortening associated with the equinus position of the hind part of the foot and the resultant foreshortening of the shadow of the calcaneus on the roentgenogram. The posterior facet of the calcaneus in the subtalar joint in the club foot is inclined in a direction reverse to that of the flat foot, so that the facet is higher on the medial side and lower on the lateral side. The superior surface of the sustentaculum tali is markedly elevated in the club foot and may be so high that it cannot be visualized in the routine posterior tangential view. From birth, the calcaneus is inverted under the talus, and the ossified portion of the talus appears to be completely supported by the ossified portion of the calcaneus (Fig. 10).

SUMMARY AND CONCLUSIONS

This study has permitted some tentative conclusions. First, it has demonstrated the normal development of the ossification centers of the calcaneus and talus as seen roentgenographically in the posterior tangential view. In the neutral foot the posterior facet appears at the age of six months, and the sustentaculum tali appears between one and two years of age and is fully developed at four or five years. The superior surfaces of both these structures lie in the horizontal plane, and there is a definite step between them caused by the elevation of the sustentaculum tali above the subtalar joint. Second, differences have been demonstrated in the development of neutral, flat, and club feet. In the flat foot, the calcaneus is everted, the subtalar-joint surface is inclined medially, and the sustentaculum tali is lowered. The talus does not appear to be adequately supported. In the club foot, the calcaneus is inverted, the subtalar joint inclines in the reverse direction, and the sustentaculum tali is markedly elevated. Third, this study has provided additional roentgenographic criteria for the diagnosis of these deformities and indicated the usefulness of the posterior tangential view as an aid in such diagnosis.

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The Treatment of Oblique Fractures of the Fibula

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It might appear that a report on so frequent an injury as the simple oblique fracture of the fibula would be unnecessary. Most such fractures heal well when immobilized in a plaster-of-Paris boot. However, familiarity with this injury should not permit us to hold it in contempt. This fracture can be treacherous, for what at first appears to be a well aligned oblique fracture of the fibula may later show widening of the mortise and lateral displacement of the talus, despite prompt treatment by immobilization in a plaster-of-Paris boot. When the talus is hypermobile and unstable in this manner, I prefer to call the condition lateral ankle instability. The diagnosis may be missed in the usual roentgenograms made after an injury but will be apparent if lateral-rotation, stress roentgenograms are made [2,8,9,10]. When the possibility of this lesion is suspected, the diagnosis may be made frequently and early. When the lesion is found early, it can be easily treated by non-operative means, with every prospect of a good result. If the diagnosis is delayed or missed, the prognosis is placed in jeopardy. The purpose of this report is to call attention to this condition and to describe the method I use to treat it.

Whether an ankle with an oblique fibular fracture will show lateral instability depends on the extent and nature of the ligamentous damage and not on the bone injury alone. The anatomy of the ankle joint, as it pertains to the stability of the joint and the mechanism of ankle injury, was discussed in a previous report [9] and needs only to be summarized here. In lateral ankle instability, the anterior and middle fibers of the medial collateral ligament, the anterior and posterior tibiofibular ligaments, the inferior transverse tibiofibular ligament, and the interosseous ligament and membrane are torn. Lateral rotation of the foot, or medial rotation of the leg when the foot is fixed, tears these ligaments in sequence and is the most frequent force to cause lateral ankle instability. Excessive eversion of the foot will tear these same ligaments simultaneously, rather than sequentially. The fibula fractures at the most proximal level of the tear in the ligaments. Thus, lateral ankle instability may accompany a fracture of the fibula at any level from the syndesmosis proximally.

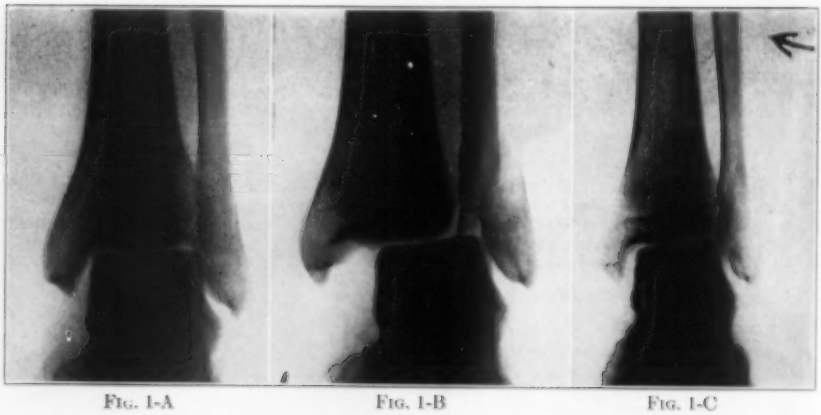

FIG. 1-A FIG. 1-B FIG. 1-C

Fig. 1-A: Anteroposterior roentgenogram of an oblique fracture of the distal portion of the fibula. No displacement of the fracture or the talus is seen.

Fig. 1-B: Same ankle with lateral-rotation stress. The proximal fibular fragment remains in the groove on the lateral aspect of the tibia. The distal fibular fragment is displaced slightly; the talus is displaced markedly, indicating +++ lateral ankle instability (see text).

Fig. 1-C: Same ankle. Stress films after six weeks of immobilization in a toe-to-mid-thigh plaster cast, which was applied in two sections with 15 to 20 degrees of medial rotation of the lower section of the cast (see text).

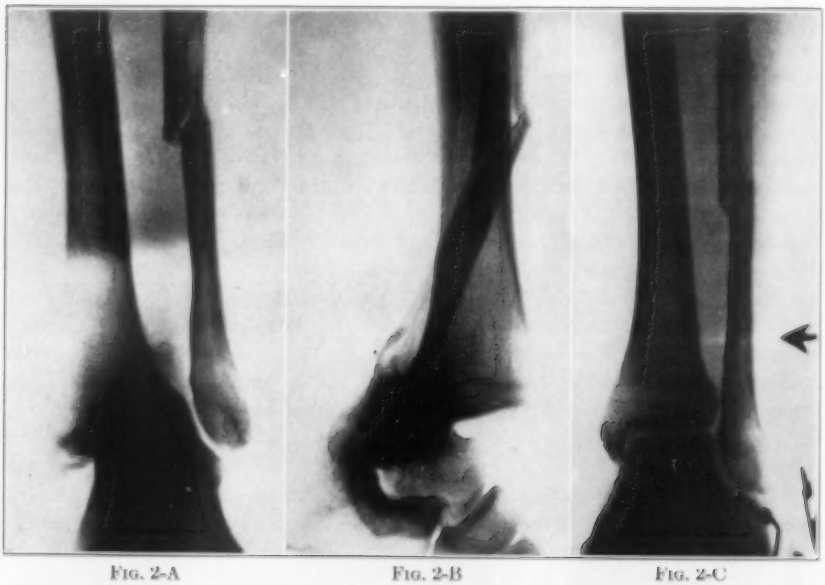

FIG. 2-A FIG. 2-B FIG. 2-C

Fig. 2-A: Anteroposterior roentgenogram of comminuted fracture of the fibular shaft with displacement of the distal fragment of the fibula from the groove on the lateral aspect of the tibia, diastasis of the ankle, and posterolateral dislocation of the talus.

Fig. 2-B: Lateral roentgenogram showing posterior dislocation of the talus.

Fig. 2-C: Stress roentgenogram after two months' immobilization in a medial-rotation plaster cast showing good stability with no diastasis or lateral talar displacement.

Much emphasis has been placed on inversion instability of the ankle due to tear of the lateral collateral ligaments of the ankle [2,16], but this must be differentiated from lateral ankle instability. The former is manifest by inversion tilting of the talus when inversion stress is applied; the latter is manifest by lateral displacement of the talus when a lateral rotation stress is applied (Figs. 1-A and 1-B).

This report concerns only lateral ankle instability. The word *diastasis* has been used to describe widening of the mortise, but I prefer to distinguish it from lateral ankle instability and shall use *diastasis* to refer only to spreading of the distal tibiofibular syndesmosis (Fig. 2-A). Lateral ankle instability or a lateral shift of the talus with widening of the space between it and the medial malleolus may be present with or without widening of the syndesmosis. Thus lateral ankle instability may exist without diastasis if the fibula fractures at or below the syndesmosis. If the fibula fractures at a higher level, the distal fragment remains within the tibial groove but rotates within the groove sufficiently to allow the talus to shift laterally.

DIAGNOSIS

Clinical examination may help to suggest the diagnosis and is most helpful soon after injury, before swelling and muscle spasm have masked the picture. When an ankle is stable, it is most tender at the fibular fracture and less tender over the deltoid and tibiofibular ligaments. The procedure for the clinical testing of lateral ankle instability is as follows: the patient is seated on an examining table, with his knees flexed 90 degrees over the side. The examiner holds the foot at a right angle to the leg and gently rotates it laterally. If there is no instability, this will cause the patient little or no additional pain, and the talus will not move away from the medial malleolus. If, however, the ankle is unstable, the patient will have an increase in pain in the region of the torn deltoid ligament and at the inferior tibiofibular syndesmosis where either the anterior tibiofibular ligament or both the anterior and posterior tibiofibular ligaments are torn. The patient will have increased pain on both the medial and lateral aspects of the ankle, and the talus may be felt to move laterally away from the medial malleolus. The ankle will be tender at the fibular fracture and at the injured ligaments, namely, the deltoid and the tibiofibular ligaments. A stable ankle does not indicate a total absence of ligamentous injury but, instead, an injury insufficient to interfere with the functional integrity of the ankle joint. I have selectively cut ligaments in the anatomical laboratory and found that, before even a small amount of lateral shift of the talus can be demonstrated roentgenographically when lateral-rotation stress is applied to the foot, the deltoid ligament and the anterior tibiofibular ligaments must be completely cut. It should be noted that lateral displacement of the talus may be seen in an anatomical specimen after only the deltoid ligament has been cut, but this displacement is not enough to be visible on the roentgenogram.

Although the clinical examination may suggest lateral ankle instability, it should be confirmed by the demonstration of lateral displacement of the talus as seen roentgenographically. Lauge-Hansen and Bonnin described the use of roentgenograms made while lateral-rotation stress is applied. I have used such roentgenograms since 1944, but, to improve and standardize the technique and to avoid exposure of the technician to roentgen rays, I developed a simple apparatus [8,9] which consists of a flat, stainless-steel footplate which is mounted on a pivot and which may be attached to the x-ray table. To the footplate there is attached a cup made of plastic into which the heel fits. The patient's foot is strapped to the foot holder, and the cassette is placed behind the ankle to make an anteroposterior roentgenogram. The patient then turns his body toward the uninjured side, rotating the leg medially while the foot remains fixed and laterally rotated relative to the leg (Fig. 3); an anteroposterior roentgenogram of the ankle is made with the foot in this position. Anesthesia is unnecessary if the patient turns carefully without forceful assistance. No anesthesia was used for any of the

roentgenograms reproduced here. If necessary, inversion or eversion stress may be applied with the same apparatus by manipulating the handle attached to the footplate. After the stress roentgenograms are made, the foot is removed from the foot holder, and lateral or other roentgenograms are made. When lateral ankle instability is present, the roentgenograms made with lateral-rotation stress on the ankle will demonstrate lateral shift of the talus (Figs. 1-A and 1-B).

TREATMENT

The essential factor which will determine the treatment required for an oblique fracture of the fibula is the presence or absence of instability. When the ankle is stable, it is sufficient to apply a lightly padded and well molded plaster boot from the toes to below the knee. Weight-bearing is avoided for the first two

FIG. 3

The foot is strapped in the stress apparatus. To apply lateral-rotation strain the patient is asked to turn on his uninjured side. With the foot held in the apparatus this movement twists the foot and ankle into lateral rotation.

weeks, then a new and similar plaster boot is applied with one of the rocker-type rubber walking heels which are commercially available. The cast is worn for another four weeks during which weight-bearing is permitted. Walking irons, pegs, or pivoting devices of any kind should not be used because the patient finds it easier to clear the ground with his toes by lateral rotation of the foot than by the more normal heel-and-toe rocker motion. Such lateral-rotation movements in a below-the-knee plaster boot may strain the ankle ligaments. After six weeks, the plaster boot is removed, and an adhesive strapping or an elastic bandage is applied. The patient is then permitted to walk but must be taught to walk correctly from the start. Most patients regain a normal range of ankle motion very rapidly, but, if necessary, physical therapy may be used to assist them to regain ankle motion. When the ankle is stable, the results of treatment of oblique fractures of the fibula are uniformly good.

When lateral ankle instability is present, adequate treatment should be started as soon after the injury as possible. Delay of a few days may permit the torn ligament ends to become scarred and prevent or delay normal healing. In a

FIG. 4-A

FIG. 4-B

Fig. 4-A: Fracture of the distal portion of the fibula immobilized in a below-the-knee plaster cast. There is no displacement of the fibula or talus.

Fig. 4-B: Same ankle with lateral-rotation stress applied to the plaster boot. The fibula is not displaced completely from the groove on the lateral aspect of the tibia, but there is ++ lateral displacement of the talus (see text).

FIG. 5-A

FIG. 5-B

Fig. 5-A: Plaster boot applied to just below the knee. Plaster must end short of the padding.

Fig. 5-B: Same plaster boot extended to mid or upper thigh, with the lower segment of the cast and the foot medially rotated 15 to 20 degrees. The circle outlines the patella, the center of which is now in line with the fourth or fifth toe instead of with the second toe.

fresh injury, the displaced talus and distal fibular fragment can be reduced without difficulty by rotating the foot medially. I have not seen a fresh injury in which the torn superficial portion of the deltoid ligament was displaced between the medial malleolus and the talus in such a manner as to prevent reduction. There is, of course, torn ligamentous tissue at this site whenever there is instability be-

cause the very short and strong deep middle portion of the deltoid ligament extends from the medial malleolus to the bare non-articular area on the medial aspect of the talus, just below the medial articular surface (Figs. 8-A and 8-B). These torn fibers are too short to act as a mechanical obstruction to reduction of the displacement. After reduction, the ankle must be adequately immobilized to prevent redislocation. A plaster-of-Paris boot is not sufficient immobilization because it permits axial rotation which can displace the talus despite the boot (Figs. 4-A and 4-B). The plaster cast must extend at least to the mid-thigh and hold the knee flexed to about 150 degrees and the foot medially rotated about 15 to 20 degrees. In principle, this plaster cast is similar to that advocated by Cochrane and is applied in the following manner: the patient is seated on the edge of a table, with the knees flexed over the side; and a lightly padded, well molded plaster cast is applied from the toes to below the knee, with the foot at a right angle to the ankle joint, neither inverted nor everted (Fig. 5-A). When the plaster has set, the plaster boot and hence the foot is rotated medially 15 to 20 degrees and the plaster is extended to the middle of the thigh while the boot below the knee is held in medial rotation (Fig. 5-B). Greater medial rotation does not help and may be painful or cause pressure sores. This procedure may be successfully used without anesthesia if the dome of the talus still articulates with some portion of the distal tibial articular surface but, if the talus has been completely dislocated or if some obstacle prevents reduction, anesthesia may be necessary to reduce the dislocation of the talus. In exceptional cases, closed reduction may be blocked by displacement of the posterior tibial tendon either between the medial malleolus and the talus [6] or between the distal ends of the tibia and fibula at the syndesmosis [1,12], or reduction may be prevented by dislocation and fixation of the fibula behind the posterior tubercle on the lateral aspect of the tibia [3,7,11]; in such cases, operative reduction is indicated. After reduction, whether open or closed, a toe-to-mid-thigh plaster cast, with the foot in medial rotation, should be applied and worn for at least four weeks and in some cases as long as eight weeks, depending on the extent of ligamentous damage. The patient is permitted to walk with crutches, but without weight-bearing. The toe-to-mid-thigh plaster cast is then removed and the stress roentgenograms are repeated. If the initial stress roentgenograms show the medial joint space of the ankle to be three-quarters of an inch or less in width the repeat stress roentgenograms are made at four weeks. Patients with more extensive instability or more talar displacement initially are kept in the toe-to-mid-thigh plaster cast for six or eight weeks before the stress roentgenograms are repeated. If the repeat roentgenogram shows the ligaments to be healed additional stress roentgenograms are not ordinarily made. In a few cases stress roentgenograms were repeated and showed no change. I would not discontinue immobilization without being certain that the ankle is stable. Experience has shown that these periods of immobilization are adequate for ligament healing and that stress testing in the manner described does not impair healing. If stability is not restored by this time, the prognosis must be guarded. If the ankle is stable, a below-the-knee plaster walking boot is applied, with a walking heel, for an additional two weeks. On removal of this plaster boot, the patient is treated in the same manner as one with a stable fracture to restore function.

MATERIAL

This study includes thirty-seven consecutive patients with oblique fibular fractures with lateral ankle instability treated by me according to the principles described. Complete data were available for every patient, including pretreatment roentgenograms showing a lateral shift of the talus either on stress or on standard

roentgenograms, and stress roentgenograms made at the end of treatment (Figs. 1-A through 2-C). Patients treated by other methods will not be reported but will be used for comparison and illustration *.

There were thirty-five male patients, one woman, and one girl of fourteen. Most of the patients were young adults in the twenties or thirties, although two were over forty, the oldest being forty-eight. All patients were active and in good physical condition. In all patients the trauma was adequate to cause fracture; there were no pathological fractures. The mechanism of injury was a force either in eversion or lateral rotation [5,9].

DEGREE OF INSTABILITY

Before the efficacy of this method of treatment can be determined, the criteria employed to characterize lateral ankle instability must be defined. In the normal adult ankle, no lateral shift of the talus is seen roentgenographically when lateral-rotation stress is applied [2,10]. The space between the medial articular surface of the talus and the lateral surface of the medial malleolus has the same width as the joint space between the dorsal surface of the talus and the inferior surface of the tibia and usually measures less than one-eighth of an inch on the standard roentgenogram. When this medial joint space is widened by stress to more than three-sixteenths of an inch, the talus is assumed to have shifted laterally and instability is present. For convenience of comparison, we have considered the instability to be + when the medial joint space was between three-sixteenths and one-quarter of an inch wide; ++ when the space was one-quarter to three-quarters of an inch wide; +++ when the space exceeded three-quarters of an inch, but the talus still maintained contact with the articular surface of the tibia; and ++++ when the talus was completely dislocated from under the articular surface of the tibia. The instability in the thirty-seven fractures was + in twenty-two, ++ in eleven, +++ in two, and ++++ in two.

It is to be noted that, if lateral displacement of the talus was evident on the first roentgenograms, which were made without lateral-rotation stress, then additional lateral-rotation stress roentgenograms were not always made, and the maximum widening of the mortise was therefore unknown. These patients were graded according to the amount of visible shift of the talus although in some of these the amount of talar shift would have increased with stress.

RESULTS

Before the end of treatment, all patients had lateral-rotation stress roentgenograms and the greatest possible mortise widening was demonstrated. Initially, all the fresh fractures with lateral ankle instability were reduced and normal contact of the talus with the medial malleolus was restored. The ankles of two patients, one showing a + displacement and the other showing a ++ displacement initially, were demonstrated to have minimum talar instability at the end of treatment, an indication that the deltoid ligament had healed with excessive length. The first ankle was treated with a plaster boot because instability was not recognized until two days later when roentgenograms of the ankle in the plaster boot showed + displacement. A second reduction was then carried out and the ankle immobilized in a toe-to-mid-thigh plaster cast, with the foot in medial rotation. After eight weeks in this long plaster cast and two weeks in a plaster boot,

* Not included are patients with fractures of the medial malleolus with lateral displacement of the malleolar fragment because, in such cases, the medial collateral ligaments are not torn but have avulsed the medial malleolus from its base to permit lateral displacement of the foot. In one of the patients included, there was an undisplaced fissure fracture of the medial malleolus with lateral ankle instability.

FIG. 6-A FIG. 6-B

Anteroposterior and lateral roentgenograms made several years after oblique fracture of the fibula. Note residual lateral talar displacement and secondary traumatic arthritis.

there was still + displacement of the talus. The other patient was seen the day after injury, at which time the leg and ankle were markedly swollen. Several roentgenograms under various conditions of stress were made, and + + displacement was demonstrated. A medial-rotation plaster cast was applied two days after injury. Although the patient wore this for ten weeks, his ankle still showed + instability when it was tested at the conclusion of treatment. This last patient was the only one of the series with functional disability. The involved leg remained markedly swollen and the condition resembled lymphedema. His disability was sufficient to prevent his return to full military duty.

The other thirty-six patients all returned to their normal military or civilian duties, with minor or no symptoms and no interference with function. Thirty-five did this within fourteen to sixteen weeks; treatment for the remaining patient was started elsewhere and he wore a plaster-of-Paris boot for seventeen days. At this time he came under my care and his ankle was still unstable and displaced. The ankle was immobilized in a medial-rotation plaster cast for four more weeks; the fracture and ligaments healed and normal function was regained about six months after injury. As a rule, the patients in military service were asymptomatic a little faster than those in civilian life, even though most of the military personnel had to return to rigorous military duties. This more favorable course was probably due to the fact that treatment of the military personnel was instituted within a few hours of injury, whereas treatment of civilian patients was often delayed.

DISCUSSION

The results of this method of treatment have been very satisfactory. If the instability was discovered and treatment was instituted early, the ligaments and the fractures healed well and the ankles became stable (Figs. 1-A through 2-C). Although I have not followed any of my own patients with persistent lateral ankle

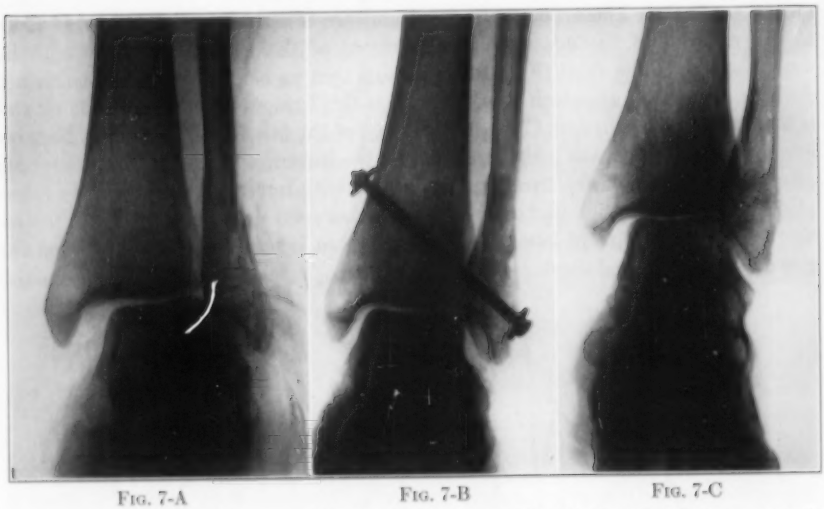

FIG. 7-A FIG. 7-B FIG. 7-C

Fig. 7-A: Fractured distal part of the fibula with lateral talar displacement, but no apparent tibiofibular separation. No stress roentgenogram was made.

Fig. 7-B: Five months after tibiofibular fixation with a bolt. The ankle was painful; there is no apparent mortise defect. No stress roentgenogram was made.

Fig. 7-C: Seven months later, after the bolt has been removed, roentgenograms made without stress show talar displacement. The ankle is still painful.

instability, it is my impression from observing other patients that if instability is untreated or discovered after the formation of scar tissue about the ends of the torn ligaments, some impairment of function often remains. The symptoms due to residual instability vary with the extent of the instability and the patient's ability to compensate for the defect. Although some patients may get along with instability of the ankle for many years, it seems probable that disabling hypertrophic arthritis will eventually develop (Figs. 6-A and 6-B).

The results obtained in this series indicate that surgery for the early treatment of lateral ankle instability is usually unnecessary. Rarely, when some obstruction prevents closed reduction of the displacement of the talus by manipulation, operation is necessary to relieve the obstruction. Under these circumstances, after the displacement of the talus has been reduced, some method of surgical repair might be considered. Open reduction and internal fixation of the fibular fracture [13], or fixation of the fibula to the tibia with a screw or bolt [2,4], have been described. The latter is not entirely innocuous; it may cause sufficient narrowing of the ankle mortise to restrict dorsiflexion of the ankle. If the bolt is extremely tight, bone absorption will occur about the bolt and pressure necrosis of the tibia and fibula may result. Fixation of the fibula to the tibia eliminates function of the distal tibiofibular syndesmosis. Loss of this function impairs dorsiflexion of the foot and deprives the ankle of its elasticity during eversion or supination, thereby impairing the ability of the foot to accommodate to irregular surfaces during walking. If the fibula is fixed to the tibia, it is necessary to remove the fixation device when the fracture and ligaments have healed [2,4]. However, neither open reduction and internal fixation of the fibular fracture nor internal fixation of the tibiofibular syndesmosis repairs the defect in the torn medial ligaments [4]. Therefore, these procedures may have no effect on the instability which will persist despite internal fixation if the ligaments fail to heal (Figs. 7-A, 7-B, and 7-C).

Surgical repair of the medial collateral ligaments has been advocated [4,14,15]. The deep middle fibers of the deltoid ligament hold the talus firmly against the

medial malleolus. These fibers are short and are attached to the bones so close to the margins of the adjacent joint surfaces of the medial malleolus and the medial aspect of the talus (Figs. 8-A and 8-B) that an efficient suture is extremely difficult. A surgical approach for the repair of this ligament posterior to the medial malleolus was described by Close, but in most of the other cases reported the thinner anterior extension of this ligament, or the anterior tibiotalar ligament, was sutured. When an old fracture that has healed with lateral ankle instability is explored, one finds a thick pad of fibrous tissue between the talus and medial malleolus. This is not ligament turned into the joint but is scar tissue that has filled the gap created by lateral displacement of the talus. To achieve healing of the medial

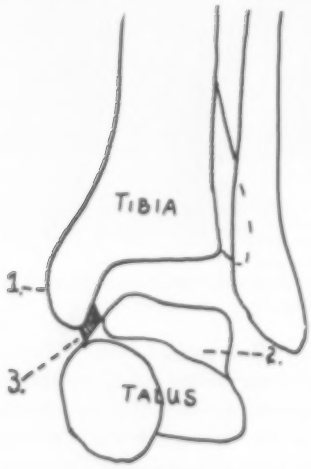

FIG. 8-A

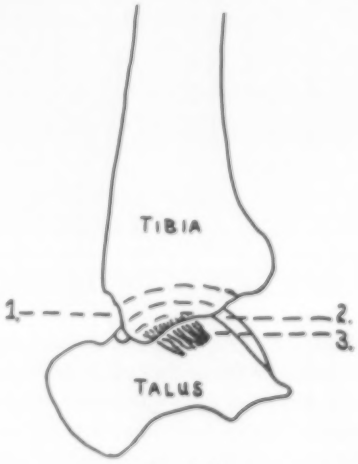

FIG. 8-B

Diagrams to show the deep tibiotalar fibers of the medial collateral (deltoid) ligament. The front view (Fig. 8-A) with talus inverted shows the fibers extending from the lateral aspect of the medial malleolus to the non-articular surface of the medial aspect of the talus. The medial aspect (Fig. 8-B) shows the same fibers (*1*, medial malleolus; *2*, articular surface of the talus; and *3*, deep tibiotalar fibers of the medial collateral ligament).

collateral ligament, even after surgical repair, the ankle must be immobilized efficiently. My experience has indicated that, in recent injuries, satisfactory healing will occur with proper immobilization without surgery (Figs. 1-A through 2-C).

A complete discussion of the reconstruction operations for residual lateral ankle instability is not the purpose of this article. In two patients, reconstructions were attempted, using the posterior tibial tendon to restore the medial collateral ligament. Neither patient had a satisfactory result. Prompt recognition and adequate treatment of the fresh injury offer the best chance for a good functional and anatomical result.

SUMMARY

To provide adequate treatment for patients with oblique fractures of the fibula, the extent of ligamentous damage must first be determined. This is best done by making lateral-rotation, stress roentgenograms of the ankle. If the ligamentous damage is not sufficient to impair stability, a plaster-of-Paris boot to below the knee provides sufficient immobilization. If, however, the damage is sufficient to create lateral ankle instability, then, after the displacement of the talus has been reduced, the ankle must be immobilized in a plaster cast that ex-

tends above the flexed knee. This holds the foot in slight medial rotation and prevents lateral rotation and displacement of the talus and distal fibular fragment. Such non-operative treatment has given almost uniformly satisfactory results, especially when used soon after injury and before the torn ligament ends are surrounded by scar tissue. Occasionally, surgery may be necessary to reduce the displacement of the talus, but operative repair of the ligamentous injury is not required.

There is, apparently, no reconstructive operation for persistent lateral ankle instability which offers results as good as those achieved by the proper initial treatment; therefore, early recognition of the injury and appropriate treatment are urgent.

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DISCUSSION

Arthrodesis of the Hip

(Continued from page 938)

Dr. Lipscomb: (closing): Arthrodesis of the hip is by far the most technically difficult operation discussed here this afternoon. It is a major surgical procedure. Someone once said that the incidence of successful arthrodesis of the hip appears to be directly proportional to the length of time that the surgeon doing the procedure has been in practice. Certainly it is a difficult procedure and I personally would hesitate to prolong it and make it more difficult technically by the use of an intermedullary nail, as discussed by Dr. Schneider. Certainly, Dr. Schneider had excellent fixation; but, for the time being, I am going to stick to some form of external immobilization, such as the single spica plaster-of-Paris cast, and allow my patients to walk, to a limited degree, within two or three weeks after surgery.

The Behavior of Autogenous and Homogenous Bone Transplants in the Anterior Chamber of the Rat's Eye

A Histological Study of the Effect of the Size of the Implant *

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Although it had been known since 1878 that grafts of homogenous bone were clinically effective [34], it was not until the introduction of the bone bank in 1942 [27] that their use was greatly stimulated. That there is a delay in the incorporation of the homogenous bone graft as compared with that of the autogenous bone graft did not prove great enough to deter clinical use. The widespread use of homogenous bone, therefore, necessitates a better understanding of the comparative behavior of autogenous and homogenous bone grafts through experimental study [15].

Experimental work has been concerned primarily with the phenomenon of osteogenesis. The effects of the various components of musculoskeletal tissue in this process have been explored, but controversy still exists whether newly formed bone can arise from the surrounding connective tissue as a result of the stimulus of the bone transplant to the host tissue or whether the new bone arises only from the tissues directly associated with the bone of the transplant or the bone of the host. Some investigators, working on the premise that an osteogenetic substance in bone induces bone formation, have studied the effect of bone extracts. Some workers claim the presence of a specific extractable organizer substance in bone [4,5,10,23,30,32,36,42,43], whereas others deny the presence of such a substance [18,25].

Modern investigators have also been concerned with the tissue reaction to various forms of dead bone treated by boiling, freezing, lyophilization, decalcification, and deproteinization [2,14,29,33,38,41]. Since emphasis has been placed on the role of tissue immunity [7] in the use of homogenous bone grafts, attempts have been made to determine the influence of tissue immunity on cell survival in transplanted bone and on the source of new-bone formation [9,14,16,17,20]. Although these avenues of approach to the problem of osteogenesis have received considerable attention, the influence of the size of the bone graft on its behavior has not been explored. It has been assumed that when a bone graft is cut into small fragments it becomes more effectual than a single large graft. Investigators have studied the fate of small autogenous bone grafts and bone shavings on both clinical and experimental levels with varying results, but adequate experimental evidence to support a preference for the small bone graft is lacking [13,28,39].

This study of large and small autogenous and homogenous bone transplants was undertaken to determine their capacity to produce new bone and the effect of the size of the bone fragment on the histological reaction of the host tissue. The anterior chamber of the rat's eye was chosen as a host bed because the implanted bone could be clearly observed and readily recovered. Use of the anterior

*These investigations were aided by grants from the Orthopaedic Research and Education Foundation, Orthopaedic Research Foundation of Seattle, and the Squibb Institute for Medical Research.

chamber of the rat's eye also excluded direct contact of the transplant with the skeleton of the host and thus served to delineate the host-tissue reaction more readily. Observations were made over an extended period of time to define the sequence of events after implantation.

METHOD

Adult albino and pigmented rats of the Long-Evans strain were used. The following types of transplant were implanted in the anterior chamber of the eye.

Group 1: Fresh autogenous cancellous bone, prepared as large fragments, averaging 2.8 millimeters in the longest dimension and one millimeter in depth and width, was obtained from the proximal half of the ilium. All soft tissue was removed by curettage before implantation.

Group 2: Fresh autogenous cortical bone, also prepared as large fragments averaging 2.8 millimeters in the longest dimension and one millimeter in depth and width, was obtained from the fibula and tibia. Care was taken to remove all soft tissue, periosteum, and marrow substance by curettage.

Group 3: Fresh autogenous cancellous bone, prepared as small fragments, varying from 0.3 to 0.7 millimeter, was obtained from the proximal half of the ilium.

Group 4: Fresh autogenous cortical bone, prepared as small fragments, varying from 0.3 to 0.7 millimeter, was obtained from the femur.

Group 5: Fresh homogenous cancellous bone, prepared as large fragments, averaging 2.8 millimeters in the longest dimension and one millimeter in depth and width, was obtained from the proximal half of the ilium.

Group 6: Fresh homogenous cortical bone, prepared as large fragments, averaging 2.8 millimeters in the longest dimension and one millimeter in depth and width, was obtained from the femur.

Group 7: Fresh homogenous cancellous and cortical bone, prepared as a mixture of small fragments varying from 0.3 to 0.7 millimeter, was obtained from the femoral metaphysis and diaphysis.

All samples were prepared under rigid aseptic conditions. The large fragments were cut to size with the aid of a rongeur and osteotome, and the particles were prepared by slow manual grinding in a mortar. The particles were then washed several times with sterile buffered salt solution. The size of the large fragments and the particles was determined by direct measurements on a calibrated scale. All soft tissue was removed from the bone before the fragments were cut or ground.

Prior to implantation, all specimens were kept in a sterile Petri dish in a few drops of Hanks' buffered salt solution containing 100 units of penicillin and 100 gamma of streptomycin per milliliter until the implantation site could be prepared. The time interval between the removal of the test specimen and implantation ranged from a few minutes to twenty minutes. The host site was prepared by dilating the pupil of the eye with 5 per cent homatropine in 1:10,000 zephiran solution, and the bone was implanted either as a single large fragment or as a paste consisting of as many particles as could be accommodated in the corneal-scleral angle of the eye opposite the incision made in the cornea. Extreme caution was taken to avoid contamination during the implantation. Sample material aspirated from the eyes to be implanted was found, on culture, to be sterile in every instance.

One of the seven types of transplant was implanted in both eyes of each of the rats used for a particular group. At least one, and usually two animals were sacrificed at intervals of one, two, three, four, five, six, eight, ten, fifteen, and

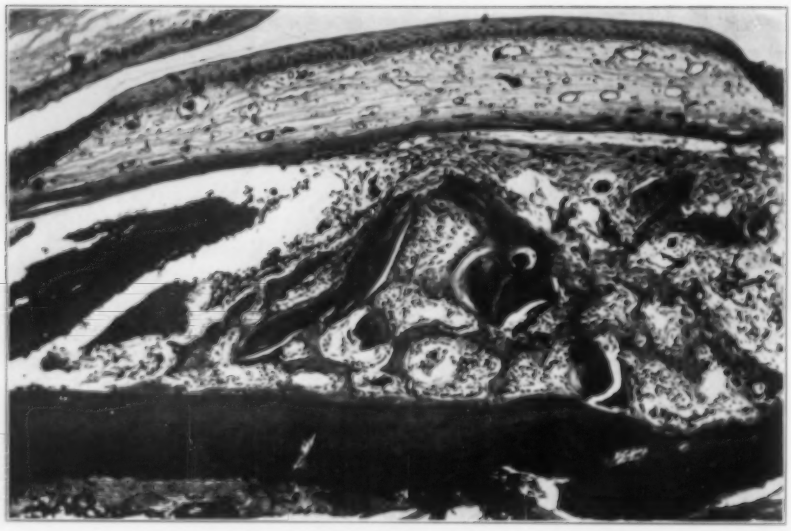

FIG. 1

Photomicrograph (× 87) of a large-fragment cancellous autograft in the anterior chamber of the eye at one week. New bone is extending from the surface of the implanted bone into the surrounding connective tissue. The lacunae of the graft are largely empty with the exception of a few remaining osteocytes on the surface, adjacent to the area of active new-bone formation. Small trabecular fragments are linked to the major fragment by this new bone.

twenty weeks after implantation. In some instances the sacrifice was thirty weeks after implantation. After sacrifice each eye was extirpated, a roentgenogram was made, and the eye specimen was fixed in Bouin's fluid. Serial paraffin sections were prepared after decalcification and were stained with hemotoxylin and eosin. A total of 178 implantations was performed.

All animals in this study received at the time of sacrifice an intracardiac injection of 2 per cent solution of Prussian blue to define the vascular pattern in the anterior chamber of the eye and the relation of the blood supply of the host to the bone implant in serial microscopic sections. A parallel study of injected specimens, cleared by the Spalteholz technique, was also carried out in each group. The details of the injection procedure and findings in Group I were reported in a previous paper [3].

RESULTS

Group 1: Large Fragments of Fresh Autogenous Cancellous Bone

All implants in this group showed the same behavior. The major portion of the implant died, as evidenced by empty lacunae and pyknotic changes in the remaining osteocytes. A few healthy-appearing surface osteocytes seemed to survive in the implanted bone for a limited time. At one week, new bone began to appear on the surface of the implanted bone in the region of the surviving surface osteocytes. This new bone extended vigorously into the surrounding connective tissue (Fig. 1). By the third week it had matured into lamellar-type bone and had begun to organize itself into a spherical mass incorporating hematopoietic marrow tissue.

By six weeks the ossicle had assumed an oval form with its long axis oriented parallel to the surface of the lens and cornea (Fig. 2). Osteoclastic resorption of the implanted bone appeared early and was most active in areas where the dead bone was not contributing to the formation of the ossicle. The dead bone was

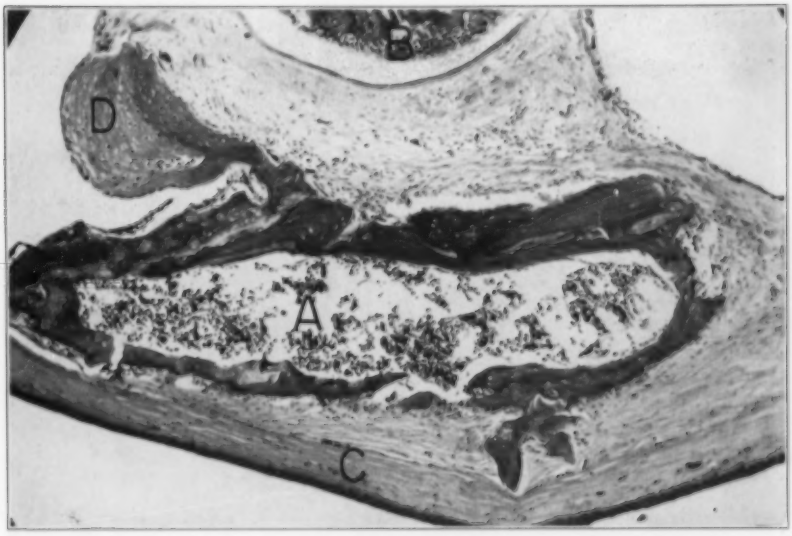

FIG. 2

Photomicrograph (×75) of a large-fragment cancellous autograft at six weeks. The growth pattern of the completed ossicle (*A*) conforms to stress between the lens (*B*) and cornea (*C*) in the anterior chamber of the eye. An area of lamellar bone with adjacent immature fibrillar bone (*D*) with an active osteoblastic border extends into the connective tissue adjacent to the lens.

FIG. 3

Photomicrograph (×95) of a large-fragment cortical autograft at two weeks. Osteocytes are still present in many of the lacunae. New bone, which is immature, remains closely attached to the surface of the implant. Osteoblastic activity around the periphery of the new bone is absent. Newly formed vascular channels are indicated by arrows.

not completely removed; some of it was present in the wall of the ossicle in the eyes examined at all periods of the experiment. After six weeks, the wall of the ossicle grew thicker as the result of appositional new-bone formation; and cement

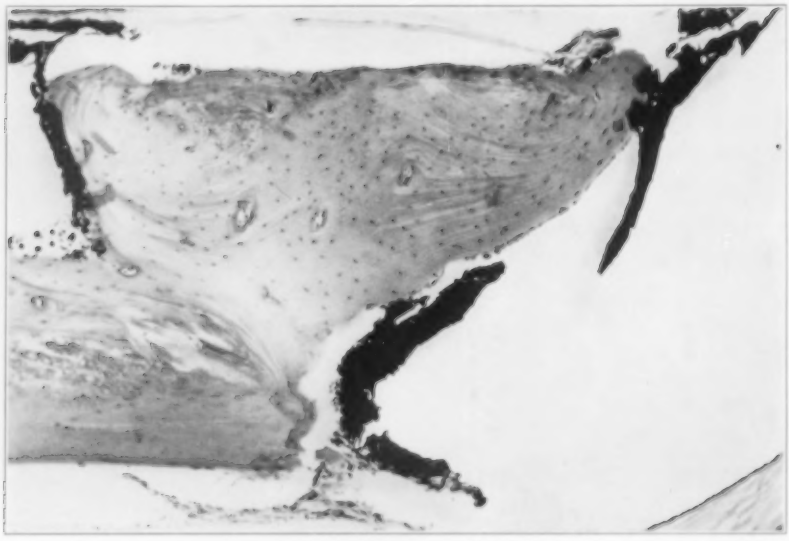

FIG. 4

Photomicrograph (×90) of a large-fragment cortical autograft after fifteen weeks in the anterior chamber of the eye. Mature, compact, lamellar bone extends from the surface of the graft in an appositional manner.

lines were frequently noted. The reaction of the host to the graft consisted of a few inflammatory cells at first, followed by rapid invasion of the area surrounding the graft by vascular granulation tissue, which was apparent at the first week. Thereafter there was little host reaction around the implant. All implants in this group demonstrated new-bone formation at all times after implantation.

Group 2: Large Fragments of Fresh Autogenous Cortical Bone

Initially, the reaction of the host to large cortical autogenous bone implants was similar to that described in Group I, with a limited number of capillaries and a few round cells visible in the vicinity of the implant. Apparently viable osteocytes in these large cortical transplants were present in greater number and were more deeply situated than the osteocytes in the cancellous bone of Group I. About the large cortical fragments, a fibroblastic tissue reaction was apparent at one week but newly formed bone was never evident at this time. A small amount of appositional new bone was present on the surface of the graft at two weeks, and vascular channels were established in the proliferating new bone adjacent to the implanted bone. The osteoblastic activity around the periphery of the new bone formed about these implants was never as active as that related to the cancellous autograft. The new-bone formation did not project into the connective tissue adjacent to the implant and was immature in character (Fig. 3). With the passage of time, the new bone increased in volume and became more mature. It was always connected to the implant which showed little tendency to be resorbed (Fig. 4). An ossicle did not form in relation to this type of implant, but in one specimen at thirty weeks, marrow substance surrounded by lamellar new bone and residual acellular bone of the original implant was noted. Multinucleated giant cells were not as prevalent here as in the ossicle formed in association with the cancellous autograft. New-bone formation was noted in twenty of the twenty-four implants in this group.

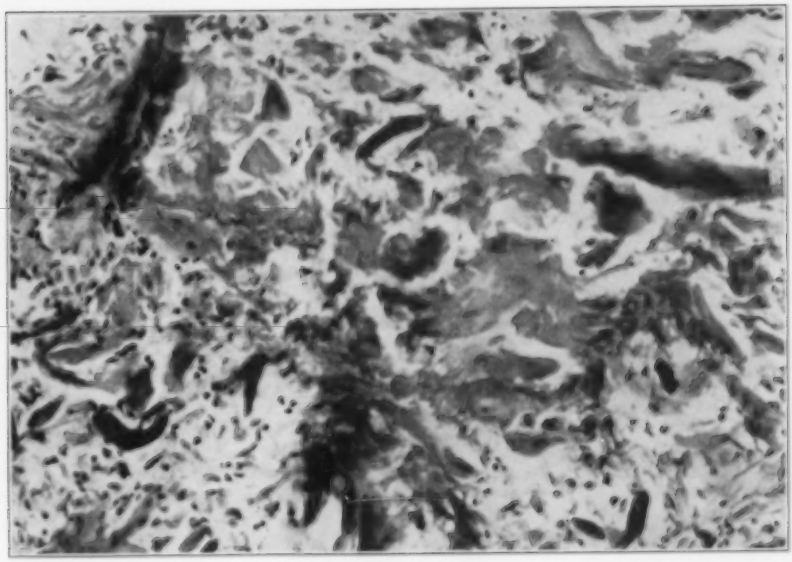

FIG. 5

Photomicrograph (×247) of small fragments of autogenous cancellous bone at twenty weeks. The fragmented bone is basophilic in staining and hardly recognizable.

Group 3: Particles of Fresh Autogenous Cancellous Bone

These implants caused a response totally different from that produced by the large-fragment cancellous autograft. No osteocytes survived in the small bone fragments, and no new-bone formation was observed. Within the first week abundant granulation tissue, inflammatory cells, and clot rapidly surrounded the bone fragments, which incited a strong foreign-body reaction. Multinucleated giant cells and histiocytes containing granular debris made their appearance at two weeks along with abundant fibroplastic cellular elements which were situated directly adjacent to the bone. Fibrous-tissue invasion around the small implanted fragments was pronounced, encapsulating each fragment and separating one from another. Thereafter the histological picture remained essentially the same until the termination of the study. The bone fragments first lost their pink-staining qualities, becoming more basophilic. They then lost their distinct fiber-like architecture, being transformed into homogeneous, fragmented, vacuolated structures (Fig. 5). Only when the transplanted fragments showed evidence of being resorbed and phagocytized did the fibrous tissue begin to disappear. There was abundant capillary proliferation in the fibrous-tissue bed surrounding the bone fragments, and the capillaries appeared to be associated primarily with the foreign-body reaction. Direct penetration of the small bone fragments by perivascular connective-tissue cells from the host was also noted.

Group 4: Particles of Fresh Autogenous Cortical Bone

The behavior of this group was similar to that of Group 3. The inflammatory reaction, however, was less intense and later in onset, not appearing until the second week. Of the twenty-five implants in this group, only one showed a scanty amount of new-bone formation at ten weeks (Fig. 6).

Group 5: Large Fragments of Fresh Homogenous Cancellous Bone

With these implants, the initial findings were very much the same as those

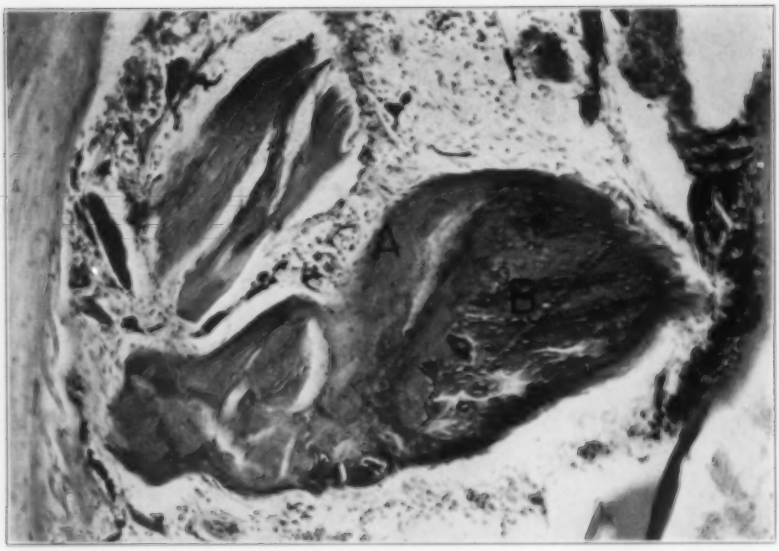

FIG. 6

Photomicrograph (×122) of small-fragment cortical autografts at ten weeks. Lamellar new bone (*A*) has developed on the surface of the acellular implanted bone (*B*).

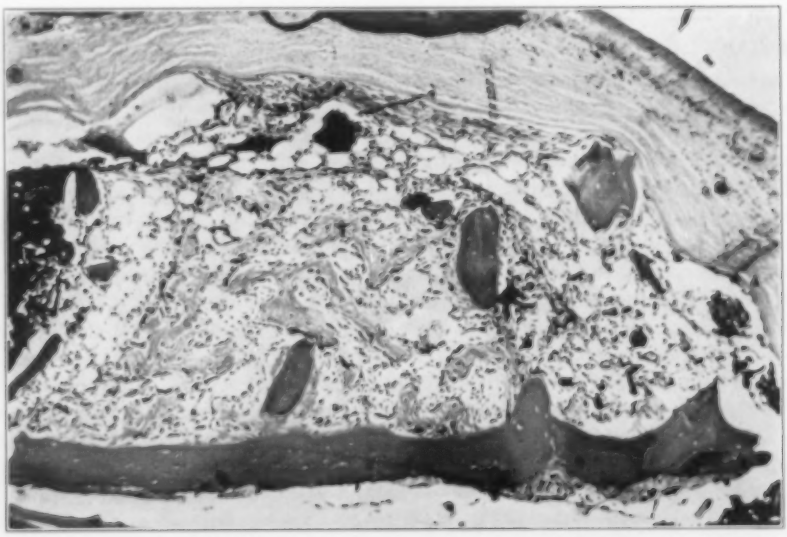

FIG. 7

Photomicrograph (×87) of a large-fragment cancellous homograft one week after implantation in the anterior chamber of the eye. New-bone formation extends from the surface of the graft. Healthy osteoblastic borders are present. Most of the lacunae in the graft are empty. Compare this with the large-fragment cancellous autograft at one week in Fig. 1.

described for the cancellous autografts in Group 1. At one week, the histological appearance of these homografts was practically indistinguishable from that of the autografts. Granulation tissue extended through the bone implant and new-bone formation was prolific (Fig. 7). A few surviving osteocytes in the implanted bone were seen up to the second week, but at this point the process of osteogenesis

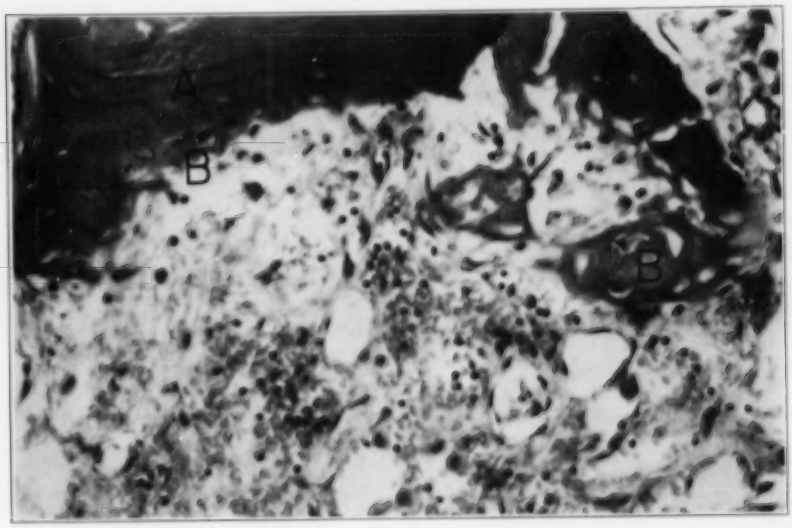

FIG. 8

Photomicrograph (×290) of a large-fragment cancellous homograft (*A*) at two weeks. On the surface layer of new bone (*B*), osteoblasts have disappeared while some of the osteocytes in the newly formed bone appear normal. Some of the lacunae of the new bone are empty, giving the appearance of a vacuolated bone matrix. An inflammatory reaction is evident.

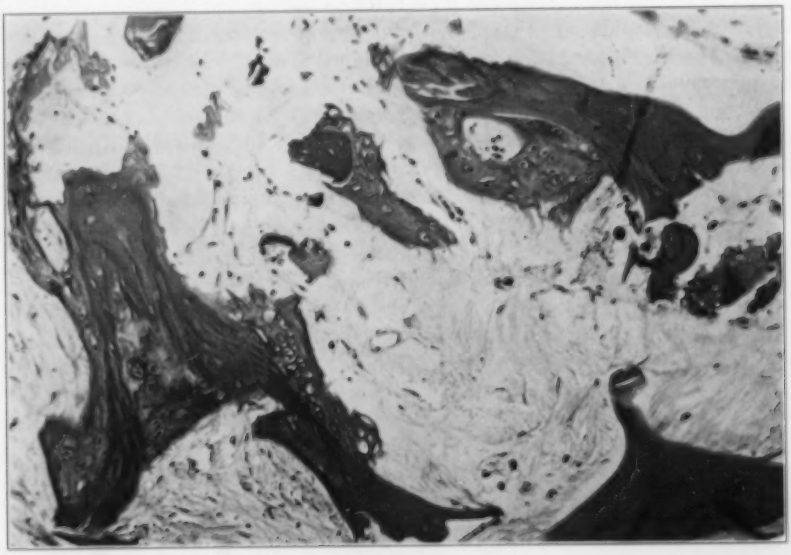

FIG. 9

Photomicrograph (×150) of a large-fragment cancellous homograft after being in the anterior chamber of the eye for eight weeks. Active late-phase new-bone formation is present in several areas arising from the surface of the trabeculae of the acellular implanted bone.

in these grafts deviated markedly from that in the autografts. Almost all of the original osteoblasts on the surface of the new bone disappeared, and the few that remained were scanty, flattened, and unhealthy in appearance. The deeper osteocytes incorporated in the new bone became pyknotic and fragmented, and they disappeared. The death of these cells created a vacuolated appearance in the

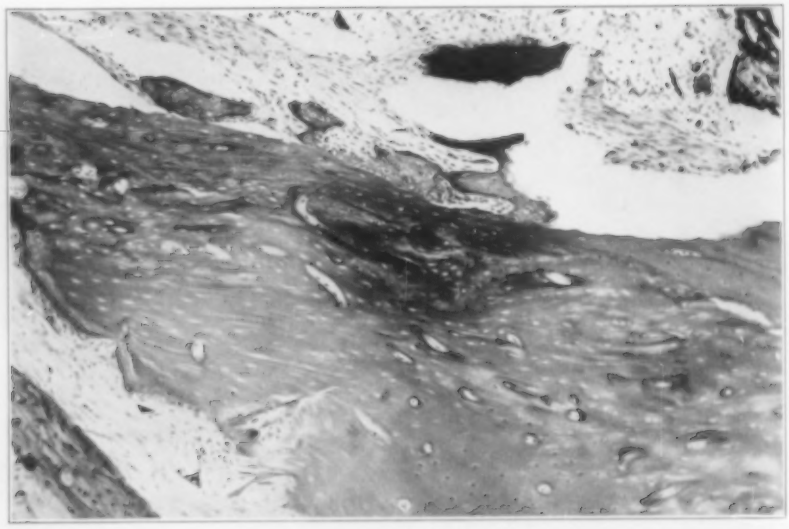

FIG. 10

Photomicrograph (×90) of a large-fragment cortical homograft in the eye at three weeks. The lacunae in the implanted bone are now largely acellular. A scanty amount of new bone extends from the surface of the graft into the surrounding connective tissue.

matrix. The new bone which had gone through this process was thus easily identified (Fig. 8). Rapid resorption of the dying new bone ensued. This transitory early phase of new-bone formation was identified in three of the four implants examined at the second week. After an interval when no new-bone formation was observed, new-bone formation reappeared at eight weeks. This second phase of new-bone formation was scanty and lamellar in character; it never became organized into an ossicle. It was closely attached to the surface of the implanted bone in an appositional manner, and a well demarcated cement line separated the new and old bone (Fig. 9). This late phase of formation was seen in association with six of ten implants examined eight weeks or more after implantation.

Multinucleated giant cells were noted at all time intervals after implantation, but resorption of the original bone was slower with the homograft than it was with the autograft. During the first week the reaction of the host tissue to the homograft resembled its reaction to the autograft. After the first week, there was a greater tendency to encapsulation of the implant by collagenous fibrous tissue. Varying degrees of inflammatory reaction occurred with infiltration by lymphocytes, plasma cells, eosinophils, and histiocytes. These cells were present throughout the period of observation. The inflammatory reaction was most pronounced from the third to the eighth week.

Group 6: Large Fragments of Homogenous Cortical Bone

The histological changes associated with this type of implant were similar to those produced by the autogenous cortical implant and, in some respects, to those caused by the homogenous cancellous implant. The amount of new bone formed was scanty and resembled that formed in relation to the cancellous homograft. At one week, no new bone was noted; when it appeared at the second week, it never proliferated into the surrounding connective tissue but remained closely associated with the surface of the cortical implant. There was a tendency for the implant to be encapsulated by fibrous tissue. Through the fourth week, osteocytes

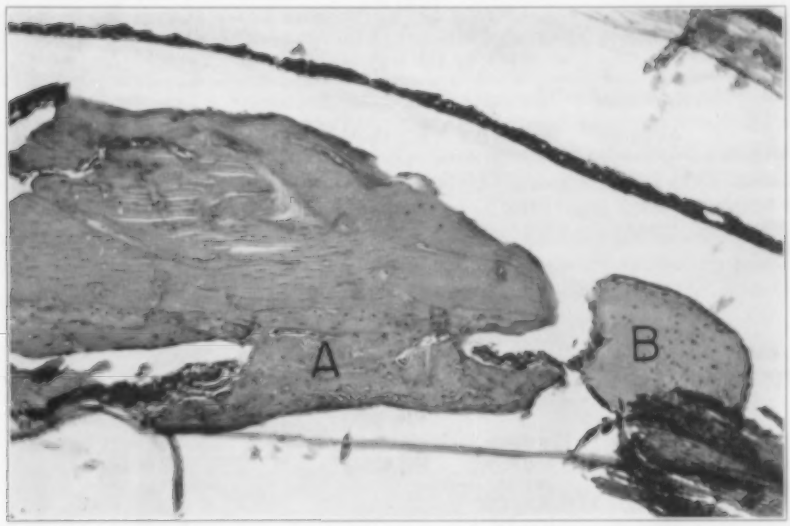

FIG. 11

Photomicrograph (×90) of a large-fragment cortical homograft in the anterior chamber of the eye at eight weeks. A combination of new mature lamellar bone (*A*) and immature fibrillar bone (*B*) are present. This is an example of late-phase new bone associated with this type of homograft.

were still visible in the lacunae of the graft. The osteocytes in these transplants persisted longer, without assuming a devitalized appearance, than did those of the cancellous homograft. The early and late phases of new-bone formation could not be delineated as well with those grafts as with the cancellous homograft. There was an overlap of early-phase new-bone formation into the fourth week after implantation but no new-bone formation was observed during the interval from the fourth to the eighth week after implantation. The new bone formed in the early phase was more lamellated in appearance and seldom showed the vacuolated appearance of dying new bone (Fig. 10). Four of the sixteen grafts examined during the first four weeks demonstrated new-bone formation, whereas eleven of the seventeen grafts examined eight weeks or more after implantation demonstrated new bone (Fig. 11).

Multinucleated giant cells were noted adjacent to the cortical bone at all times, but resorption of the transplanted bone was very slow. The reaction of the host tissue to the cortical fragment was similar to that to the cancellous fragment, but the degree of inflammatory reaction was much less.

Group 7: Particles of Homogenous Cancellous and Cortical Bone

The results of this type of implant were similar to those observed in Groups 3 and 4. The inflammatory reaction was much more intense with this than with the large fragments of homogenous bone (Fig. 12). Of the eighteen implants in this group, only one, at twenty weeks, demonstrated new-bone formation on the surface of the acellular implant typical of late-phase new-bone formation.

DISCUSSION

The findings in this experimental investigation established the behavior patterns of large fragments and particles of autogenous and homogenous bone implanted in the anterior chamber of the rat's eye. Table I lists a comparative evaluation of new-bone formation in the large-fragment autogenous and homogen-

TABLE I

A Comparison of New-Bone Formation in Implants of Large-Fragment Size Autogenous and Homogenous Bone

	Cancellous Autograft	Cortical Autograft	Cancellous Homograft		Cortical Homograft	
			Early Phase	Late Phase	Early Phase	Late Phase
Duration of new-bone growth	One to thirty weeks	Two to thirty weeks	One week to fourteen days. Dead new bone present at third week	Eight to thirty weeks	No new bone until second week—persists through the fourth week	Eight to thirty weeks
Amount of new bone	Abundant	Variable but usually scanty	Abundant at one week—thereafter scanty	Scanty	Scanty	Scanty
Appearance of new bone	Immature and woven up to two weeks, then lamellar	Immature and woven at first, then lamellar	Immature and woven	Lamellar	Immature and woven at first, then lamellar	Lamellar
Incidence	100 per cent	83 per cent	75 per cent	60 per cent	25 per cent	65 per cent
Fate of the new bone	Forms ossicle	Forms mature appositional bone	Resorbed after death	Forms lamellar plaque on surface of dead bone	Resorbed after death	Forms lamellar plaque on surface of dead bone

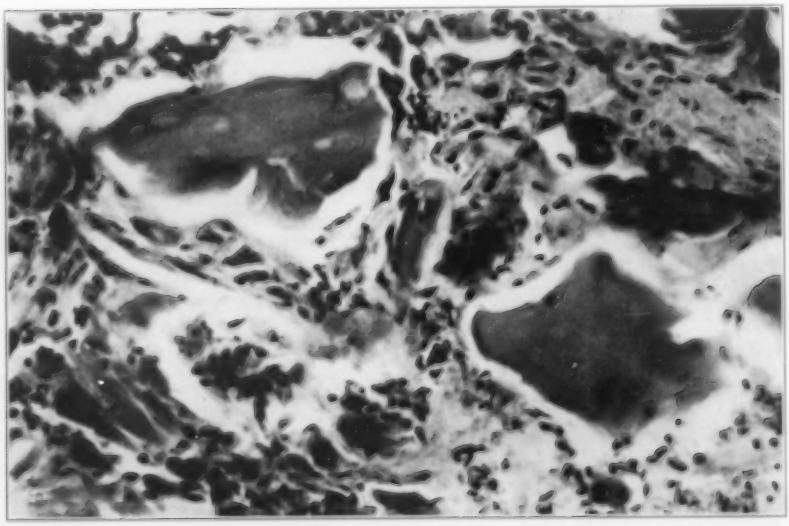

FIG. 12

Photomicrograph (×290) of small fragments of homogenous cancellous and cortical bone in the anterior chamber of the eye at one week. The graft fragments are completely acellular and are being phagocytyzed in a bed of dense connective tissue created by a fibroblastic reaction to the grafts. Inflammatory elements are present and no new bone is evident.

ous bone implants. Chart I summarizes the number of specimens demonstrating new-bone formation and its duration and distribution in the seven groups included in this study.

The survival of a few osteocytes on the surface of the bone implant, whether the implants were autogenous or homogenous, occurred when the fragment was large. Osteocytes located deep within the large cortical grafts, both autogenous and homogenous, were histologically evident for a longer period than were the deeply placed osteocytes in the cancellous grafts. This could be explained by the thickness of the matrix of the cortical grafts which may have protected these cells from contact with host cells and delayed the disappearance of the transplanted cells. None of the osteocytes survived in the small bone fragments.

A GRAPHIC COMPARISON OF THE NUMBER, DURATION AND DISTRIBUTION OF LIVING NEW BONE SPECIMENS IN AUTOGENOUS AND HOMOGENOUS BONE IMPLANTS OF LARGE AND SMALL FRAGMENT SIZE

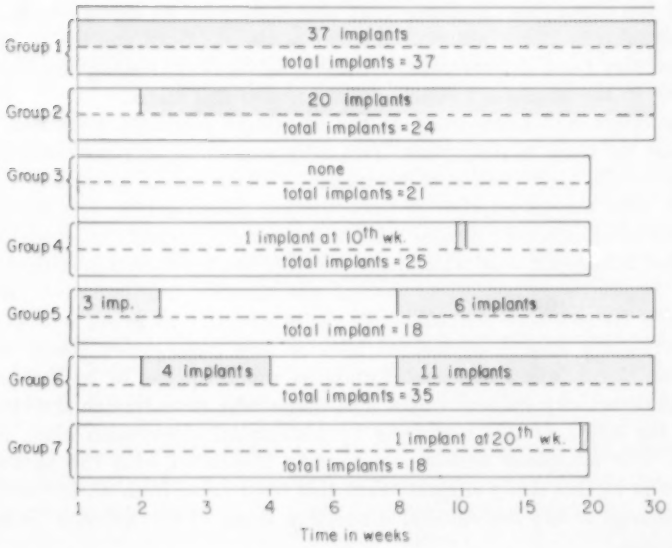

CHART I

The cancellous autogenous grafts gave rise to new bone which became organized into ossicles with hematopoietic marrow. The implanted bone which did not contribute to the formation of an ossicle was rapidly removed from the graft site and there was no inflammatory reaction. The cancellous homogenous grafts, on the other hand, gave rise to two separate and distinct phases of new-bone formation. The early phase, which at one week was similar to the new bone associated with the cancellous autograft, terminated in death of the new bone at the end of the second week. The late phase of new-bone formation appeared at eight weeks and persisted thereafter. Resorption of the implant was slower with this type of graft than with a cancellous autograft, and the inflammatory reaction which accompanied this process persisted through thirty weeks.

The findings in this study are in accord with Chalmers' observations on the behavior of the large-fragment, cancellous autogenous grafts and homogenous grafts implanted in rat's muscle, except that the late phase of new-bone formation

did not develop until the eighth week after implantation in the anterior chamber of the rat's eye, whereas in Chalmers' implants in muscle the late phase began at four weeks. Chalmers stressed that the immune response to homogenous bone is characterized by a latent period before rejection of the homograft takes place. During this latent period, the surviving osteogenic cells have an opportunity to proliferate and form new bone. The failure of early-phase new-bone formation to occur in the homograft in animals immunized before implantation of the bone by a homogenous skin graft indicated that the early-phase new-bone formation arose from cells of the graft. Chalmers' work was based on the premise that bone possesses tissue antigens that evoke a reaction in the host which then destroys the cells of the bone implant. In the study reported here, the period of survival of the early-phase new-bone formation was of interest. With the large-fragment cortical homogenous graft, the early phase persisted until the fourth week, whereas with the large-fragment cancellous homogenous graft the early-phase new bone disappeared at the second week. The reason for this may be that the cortical homogenous graft invokes a different level of immune response with longer survival of the osteocytes. Evidence that new bone may be formed by surviving transplanted cells in the anterior chamber of the rat's eye appears to be clear. This has also been demonstrated in tissue culture [21,24]. Early-phase new-bone formation in the homograft would appear to be of this origin.

The origin and histogenesis of the late-phase new-bone formation in the homograft are open to conjecture. Two main sources of this new bone may be considered—the graft itself and metaplasia of the adjacent connective tissue of the host with the assumption of bone-forming potentialities. The existence of transplantation immunity against a given homograft does not eliminate the possibility that bone-graft cells, which have survived beyond a certain critical period, may no longer be susceptible to the immune reaction and hence be viable and responsible for new-bone formation. On the other hand, there are reports of new bone developing around devitalized bone in soft tissue [19,42,45]. Under such an experimental condition, new-bone formation would appear to be the result of osteogenetic activity induced in the host-tissue cells, even though the identification of the origin of this new bone by histological observation alone may be difficult. The late-phase new-bone formation associated with the homogenous bone grafts in this study suggests that this bone arose from an induced metaplastic change in the non-skeletal connective tissue of the anterior chamber of the rat's eye.

The behavior of the large-fragment cortical grafts, both autogenous and homogenous, were similar. The new-bone formation was lamellar and scanty and did not appear until the second week. Deep osteocytes in the grafts persisted up to four weeks. The scanty amount of new bone could probably be attributed to the small surface area of these cortical grafts in contrast to the larger surface area and trabecular structure of the cancellous grafts which enhanced new-bone formation and neovascularization. The apparent longer survival of the osteocytes in the cortical bone could be explained on the basis that this compact bone excluded the host cells and protected the graft cells from the immune reaction. The two types of cortical grafts differed in two respects: the cortical homogenous graft was associated with early and late phases of new-bone formation and incited an inflammatory reaction; the cortical autogenous graft, on the other hand, demonstrated new-bone formation which continued after its initial appearance at the second week and incited no host-tissue reaction.

The more rapid and prolific growth of new bone in the cancellous graft indicated that a larger surface area was available for appositional-bone growth. From

this, it might be assumed that increasing the surface area of the graft by reducing the size of the bone fragments implanted would enhance new-bone formation. This, however, is not the case. Keith, in 1934, in order to determine the fate of the small bone graft, implanted autogenous bone shavings in defects in the radii of dogs. From these experiments he concluded that "it is fallacious to fragment a bone graft more than is necessary . . . since minute fragmentation lowers both its supporting and osteogenic functions". Siffert, in 1955, found that autogenous cortical shavings were completely destroyed as a foreign material in rabbits, the shavings seeming to play no role in new-bone formation.

The implants of autogenous and homogenous particles in this study behaved in a similar manner, causing a totally different response from that caused by the large-fragment bone implants. No new-bone formation occurred in the early stages. The majority of the grafts incited a strong inflammatory and foreign-body reaction. The implantation site was composed of dense connective tissue, and there was early and continued destruction of the fragments by multinucleated giant cells. Phagocytosis continued as the bone fragments lost their fiber-like architecture and staining characteristics to the extent that they were hardly distinguishable. Vascularization in the host-tissue bed was enhanced with this type of implant. At no time during the entire study were any surviving osteocytes observed in the lacunae of this type of bone.

Fragmentation undoubtedly alters the surface characteristics of the transplanted bone, just as it increases the surface area of transplant matrix exposed to the host tissues. The potentiation of the inflammatory reaction produced by the fragmented bone may thus be due to physical stimulation of the host tissues consequent to the small size of the particles or be due to changes in the chemical properties of the fragmented bone substance caused by the fragmentation procedure. The principal stimulus to the observed inflammatory reaction is not known; but, certainly, the fragmented bone exposes a greater surface area of bone matrix to the tissue fluid of the host bed and presumably produces a medium unsuitable for the survival of the transplanted osteocytes. There appears to be some correlation between the degree of cellular survival in the transplant and the osteogenetic potency of the transplant. In the small-fragment transplants, there was no histological evidence of cell survival and no osteogenetic activity, whereas in the large-fragment implants there was evidence of cell survival and bone-forming activity. These observations lend some support to the hypothesis that, at least in the early stages after transplantation, new bone is produced by surviving transplanted cells.

The two instances in these experiments where new bone developed late after implantation of a small-fragment autograft and a small-fragment homograft suggest that this new bone was produced as the result of metaplasia of the non-skeletal connective tissue of the eye.

CONCLUSIONS

Histological sections of 178 large-fragment and small-fragment fresh autogenous and homogenous bone implants in the anterior chamber of the rat's eye, studied for as long as thirty weeks after implantation, revealed the following:

1. Fresh large-fragment cancellous autografts gave rise to early vigorous new-bone formation which produced an ossicle incorporating marrow substance about three weeks after implantation. The shape of this ossicle appeared to be determined by the stresses in the anterior chamber of the eye. There was no inflammatory reaction, and the bone continued to grow throughout the experimental period.

2. Fresh large-fragment cancellous homografts produced early new bone, but this died at the end of two weeks. A late phase of bone formation composed of scanty lamellar new bone appeared at eight weeks and still persisted at the end of the experiment thirty weeks after implantation. A mild local inflammatory reaction was associated with this implant.

3. Fresh large-fragment cortical autografts and homografts produced scanty, lamellar new bone which was closely applied to the graft surface. The cortical homograft in contrast to the autograft produced early-phase and late-phase new-bone formation, as well as a mild local inflammatory reaction.

4. Small-fragment fresh cancellous and cortical autografts and homografts did not produce any appreciable new bone. A more intense inflammatory reaction was incited by this type of graft than by the large-fragment bone implants; this reaction enhanced the process of resorption of the small-fragment transplants.

5. The evidence from these studies indicates that cellular elements of the large-bone fragments may survive and proliferate in the anterior chamber of the rat's eye to produce new bone in the early period following transplantation. Fragmentation of bone, however, creates a medium unsuitable for cellular survival and destroys the osteogenetic activity of the graft.

6. New-bone formation brought about by metaplastic change in the host cells in these experiments appeared to be the result of prolonged direct contact with large-fragment homografts until the late-phase new-bone formation had developed. Similarly, the two solitary instances of late-phase new-bone formation associated with small-fragment grafts (homogenous cortical and cancellous and autogenous cortical) appeared to be examples of new bone induced by contact of the transplanted bone tissue with the host cells.

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The Effect of Particle Size of the Heterogenous Bone Transplant on the Host Tissue

II. A Histological Study * † ‡

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In a previous report [1], we were concerned with the vascular penetration of large and small heterogenous bone implants in the anterior chamber of the rat's eye. It was shown that small-fragment heterogenous bone grafts, in the form of paste, were penetrated by blood vessels as rapidly as the large-fragment autogenous cancellous grafts, without any particular barrier to penetration. Large fragments of heterogenous bone, on the other hand, showed surface vascularization without appreciable penetration. The host-vascular response to large-fragment heterogenous grafts was not influenced by the method of storage; the response was the same whether the grafts were fresh, stored in plasma, or stored in saline solution.

Heterogenous bone has been used as a transplant material in human patients for many years. It has been preferred by European surgeons largely because the supply is unlimited. In 1934, Orell reported the successful use of *os purum* and *os novum*, and recent reports on the clinical use of the heterogenous bone grafts have been encouraging [7,8,9,13,15].

An objection to this type of bone graft is species incompatibility. Most reports on bone heterografts have been of a clinical nature; there is a paucity of controlled experimental work. Although a transplant of this type may appear to be accepted by the host by clinical and roentgenographic criteria, the degree of acceptance must be determined histologically.

The introduction of an antigenic foreign material into an experimental animal evokes an inflammatory response which is regarded by some investigators as the reason for failure of homogenous or heterogenous bone transplants.

The purpose of the following experiments was to investigate this inflammatory response of the host by histological methods using large and small fragments of calf bone preserved in various ways and transplanted into the anterior chamber of the rat's eye. The bone implant and the osteogenesis in this ectopic site could thus be readily observed, and the inflammatory reaction of the host could be well delineated.

METHOD

Adult albino and pigmented rats of the Long-Evans strain were used, and 227 implantations in the anterior chamber of the eye were done. A summary of the experimental groups is shown in Table I.

1. The fresh cortical and cancellous calf-bone implants of large-fragment

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‡ Part of monograph "Experimental Investigations of Large and Small Fragment Bone Implants and Extracts of Heterogenous Bone" awarded the Kappa Delta Award for Research in Orthopaedic Surgery.

TABLE I

FRESH AND PRESERVED HETEROGENOUS BONE IMPLANTS
Summary of Experimental Groups

Type of Bone Implant	Fragment Size	Number of Specimens
Histological study:		
Group 1. Fresh heterogenous cancellous and cortical	Large	55
Group 2. Plasma and saline-stored heterogenous cancellous and cortical	Large	121
Group 3. Plasma-stored heterogenous cancellous and cortical	Small	29 (non-irradiated) 22 (irradiated)
Total		227

size could not be implanted until the second day after removal from the calf because of technical difficulties in transportation. The bone was shipped to the laboratory in sterile vials without refrigeration.

2. The large-fragment plasma-stored calf bone was prepared by the technique previously reported by Tucker. It was stored from six weeks to nine months at 4 degrees centigrade in homologous bovine plasma. The large-fragment saline-stored calf bone was maintained in physiologic saline solution at 4 degrees centigrade for not less than six weeks.

3. The small-fragment, plasma-stored calf bone, which included both cancellous and cortical bone, was also prepared by the method of Tucker. In this group twenty-two specimens were irradiated with 2.5 million roentgen equivalent physicals from a cathode source and twenty-nine specimens were not irradiated.

As in our previous studies the term *large-fragment* is used to indicate a single bone implant that could just be accommodated by the host bed in the anterior chamber of the rat's eye. Such a fragment averaged 2.8 millimeters in the longest dimension and one millimeter in depth and width. The term *small-fragment* designates a transplant composed of a paste of many small fragments occupying approximately the same volume of the host bed as the large fragment. The fragments in this paste measured 0.3 to 0.7 millimeter in their longest dimension.

All samples of preserved calf bone and calf-bone paste were prepared under aseptic conditions and supplied to us by the Squibb Institute for Medical Research. Fresh samples of sterile bovine bone were supplied direct to us by Dr. E. J. Tucker. The large fragments were cut to size from stock samples with a rongeur and osteotome. The bone paste was used directly from the sterile, disposable, plastic syringes in which it was received. The size of the large fragments and the fragments in the paste were determined by direct measurements on a calibrated scale.

Before implantation, the large-bone fragments were removed from the vials in which they had been preserved and placed in a sterile Petri dish containing Hanks' buffered salt solution and 100 units of penicillin and 100 gamma of streptomycin per milliliter. Histological examination and tissue culture of samples of the calf bone before implantation demonstrated no apparent living cells. With the rat under general anesthesia, the pupil of each eye was dilated with 5 per cent homatropine in 1:10,000 zephiran solution. The bone was implanted in the corneal-scleral angle opposite the incision in the cornea. Care was taken to avoid contamination during implantation. Sample cultures of material aspirated from implanted eyes did not reveal evidence of infection in any instance.

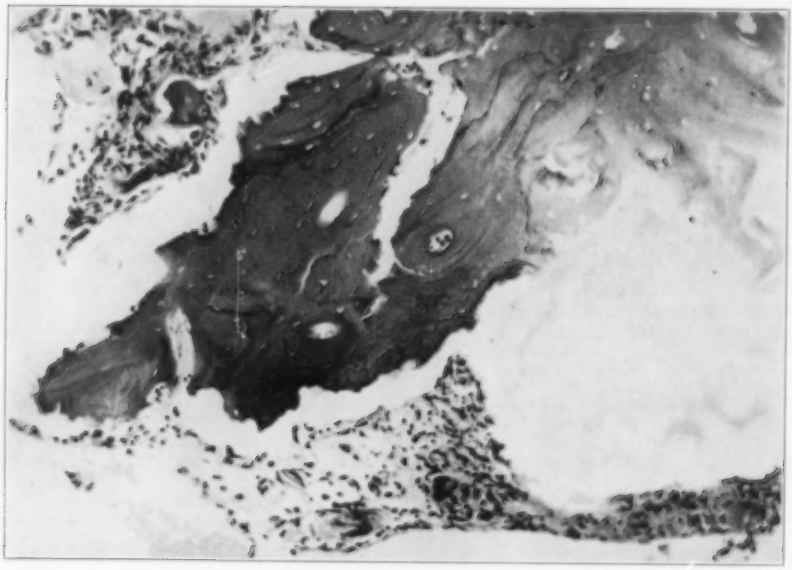

FIG. 1

Photomicrograph (× 125) of a fresh, large-fragment cortical heterograft two weeks after implantation in the anterior chamber of a rat's eye. A loose connective tissue containing multinucleated giant cells has advanced toward the bone implant. An inflammatory reaction is still present.

FIG. 2

Photomicrograph (× 250) of a fresh large-fragment cancellous heterograft which still exhibits stainable osteocytes at twenty weeks. Note the absence of any host-tissue reaction.

The same type of bone was implanted in both eyes of each rat in the various experimental groups. At least two animals (four eyes) in each experimental group were sacrificed at intervals of one, two, three, four, six, eight, ten, fifteen, and twenty weeks—in some instances after thirty and forty weeks. At the time of

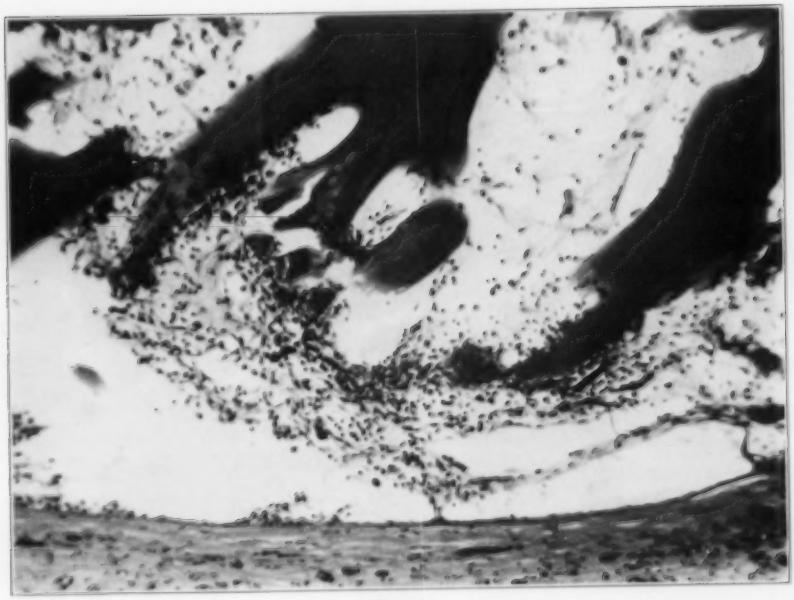

FIG. 3

Photomicrograph (× 120) of a plasma-stored large-fragment cancellous heterograft one week after implantation in the anterior chamber of the eye. No new bone is evident. The implanted bone is acellular. A loose mesh of fibrous tissue is present between the bone trabeculae. The inflammatory reaction is evident.

sacrifice, the eye containing the implant was extirpated, fixed in 10 per cent neutral formalin, and embedded in paraffin. Serial microscopic sections were made and stained with hemotoxylin and eosin.

RESULTS

Fresh Large-Fragment Cortical and Cancellous Implants

At one week pyknotic and shrunken osteocytes were still visible in some of the lacunae of the implanted cortical bone, but the majority of the lacunae were empty. In most instances there was an inflammatory reaction around the periphery of the implant consisting of mononuclear and neutrophilic leukocytes enmeshed in a loose fibroblastic connective tissue. By the second week, the histological picture was not changed except that multinucleated giant cells were now present in the connective tissue surrounding the bone (Fig. 1).

At three weeks, the relatively mild inflammatory reaction was still present; it now consisted of mononuclear, lymphocytic, and plasma cells, as well as some eosinophils. The giant cells at this time were situated directly adjacent to the implant which was completely ensheathed by fibrous tissue.

From the fourth to the tenth week, the inflammatory reaction continued. Thereafter it rapidly subsided and was absent in most specimens from the tenth week to the end of the experiment period (forty weeks). An intense inflammatory reaction, however, was noted in four of the forty specimens obtained during this later period. Two were from one rat at ten weeks; the other two were from another rat which showed this reaction at thirty weeks.

The architectural characteristics of the fresh heterogenous cortical-bone implants did not change materially throughout the study since there was little resorption. The staining characteristics of the implant remained constant, and au-

FIG. 4

Photomicrograph (× 120) of a plasma-stored large-fragment cancellous heterograft in the anterior chamber of the eye at eight weeks. Dense connective tissue lies adjacent to the smaller trabeculae of the bone implant. The inflammatory reaction continues.

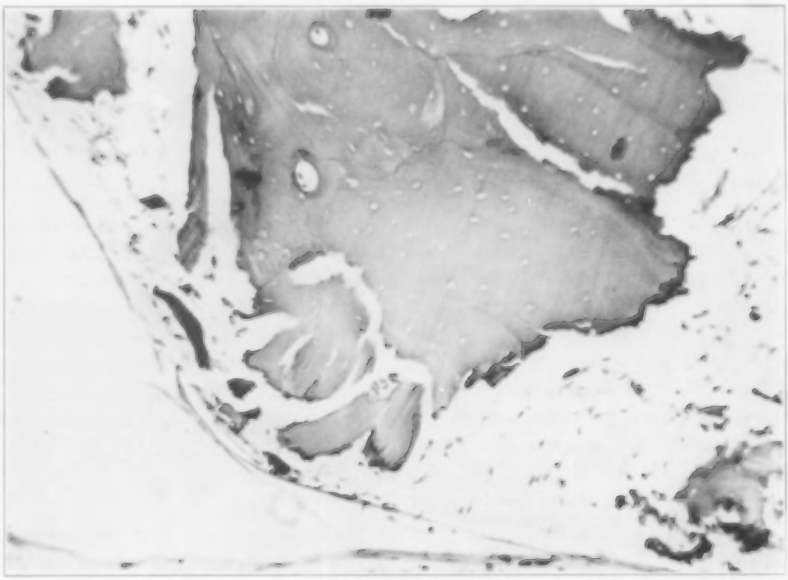

FIG. 5

Photomicrograph (× 120) of a plasma-stored large-fragment cortical heterograft at six weeks. Only a loose connective tissue surrounds the bone implant

tolysis of the bone was not particularly evident. In a few instances, osteocytes, without notable pyknotic characteristics (Fig. 2), could be identified in the lacunae of the bone implant up to the twentieth week.

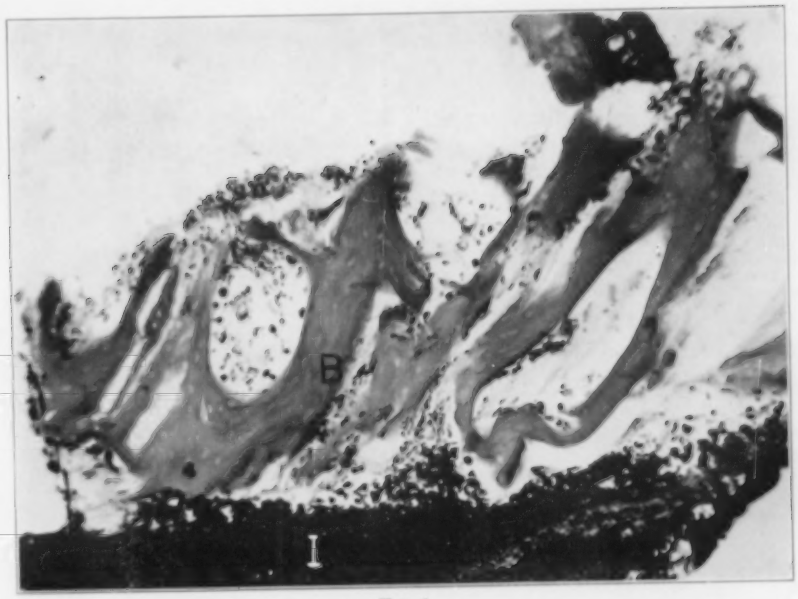

FIG. 6

Saline-stored large-fragment cancellous heterograft in the anterior chamber of the eye at two weeks; the implant has elicited very little host reaction (× 120). The implant (*B*) lies adjacent to the pigmented iris (*I*) of the eye.

No evidence of new bone or any semblance of osteogenesis was noted throughout the study.

The behavior of the cancellous heterografts resembled that of the cortical grafts, but the cancellous grafts elicited more inflammatory reaction. Multinucleated giant cells were frequently seen adjacent to the implant, their relationship indicating phagocytic activity, but little resorption occurred. The fibroblastic reaction around the implant was never dense.

Plasma-Stored Large-Fragment Cortical and Cancellous Implants

In most respects, this group behaved like the fresh large-fragment heterografts. No survival of osteocytes was noted and no new bone formed. Resorption associated with the presence of osteoclast-like giant cells progressed slowly. The local inflammatory reaction associated with these implants was always more severe with the plasma-stored heterograft than that associated with the fresh, large-fragment heterografts (Figs. 3 and 4). The preserved cancellous heterografts always elicited more reaction than the cortical types (Fig. 5). The inflammatory reaction slowly receded in intensity after the fifteenth week.

Saline-Stored Large-Fragment Cortical and Cancellous Implants

These behaved much as plasma-stored heterografts, but the inflammatory reaction after storage in saline solution was less severe than that after storage in plasma (Fig. 6).

Plasma-Stored Small-Fragment Cortical and Cancellous Implants

At one week granulation tissue and inflammatory cells were abundant. The inflammatory cells were predominantly polymorphonuclear leukocytes and lymphocytes which were oriented about the individual bone fragments. Loose connective

FIG. 7

Plasma-stored small fragments of cancellous and cortical heterogenous bone in the anterior chamber of the eye at three weeks. The inflammatory reaction is intense (× 120).

tissue surrounded the bone fragments. Multinucleated giant cells also appeared in the connective tissue at this time. By the second week these giant cells were lying directly adjacent to the bone fragments, and the encapsulating fibrous-tissue reaction had become more dense.

At the end of three weeks the degree of inflammatory reaction had intensified (Fig. 7). Thereafter, the histological picture was characterized by increasingly dense fibrous-tissue encapsulation of the bone fragments, with disappearance of the inflammatory reaction after the fifteenth week. The bone fragments maintained their fiber-like architecture and normal staining characteristics. An abundant capillary proliferation in the fibrous-tissue bed surrounding the bone fragments was evident; histologically these capillaries seemed most directly associated with the foreign-body reaction.

The small-fragment heterografts, which had been irradiated, demonstrated histological characteristics similar to those of the small-fragment implant which had not been irradiated, but the inflammatory reaction was more severe. In fact, this reaction was so severe that it resembled an abscess with inflammatory elements filling almost the entire anterior chamber of the eye, particularly during the first three weeks after implantation (Fig. 8). This reaction was in contrast to the more localized inflammatory reaction about the implants which had not been irradiated. This severe reaction continued until the tenth week and then gradually receded.

DISCUSSION

The behavior of implanted autogenous and homogenous bone in several ectopic sites [2,3,6,16] has been investigated previously. The behavior of implanted calf bone of large and small fragments in the anterior chamber of the rat's eye is established by the results reported here.

No evidence of survival of the transplanted osteocytes was observed in any of the heterogenous bone implants. The persistence of lacunar osteocytes in the

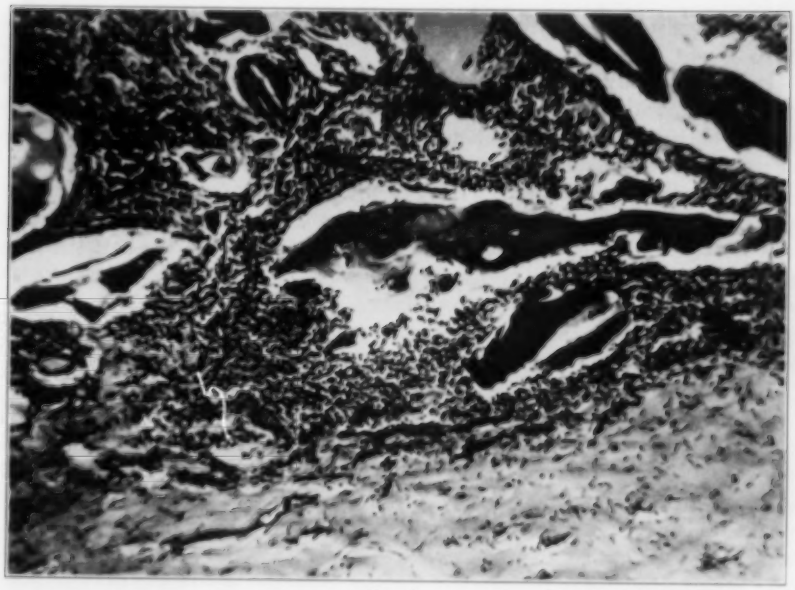

FIG. 8

Photomicrograph (× 120) of plasma-stored irradiated (by cathode ray) small fragments of cancellous and cortical heterogenous bone, three weeks after implantation in the anterior chamber of the eye. The character and intensity of the inflammatory reaction is the same as that at earlier sacrifice periods.

histological preparations of the fresh, large-fragment, heterogenous bone implants, however, was noteworthy. An empty lacuna indicates that the osteocyte has died and been removed by autolysis. However, stainable cellular material may be seen in the lacunae of sequestrated bone long after its death. The long persistence of cellular material in heterogenous transplants suggests that the matrix of implanted heterogenous bone may be impervious to the autolytic action of the host cells for prolonged periods. Resorption of heterogenous bone implants appears to be slower than that of fresh autogenous or homogenous implants, whether the fragment is large or small. Although there are frequent giant cells which, by their relation to the bone, appear to be performing a resorptive function, the architecture of the heterogenous bone did not change, thereby indicating that the process of autolysis was ineffective. These findings suggest that heterografts are less readily resorbed than the autografts and homografts but a definite conclusion concerning this point is not warranted on the basis of the methods utilized in this study.

Large-fragment fresh, plasma-stored, and saline-stored heterografts of calf bone incited different levels of inflammatory reaction. Fresh heterografts incited an inflammatory reaction which was mild and comparable to that of the fresh homograft in this experimental biological system [2,3]. Storage of heterogenous bone in saline solution caused it to produce less host-tissue reaction than a fresh heterograft. Storage in homologous bovine plasma increased and accelerated the inflammatory reaction of the host.

Small-fragment heterogenous calf-bone implants after storage in plasma manifested a behavior pattern similar to that of small-fragment implants of autogenous and homogenous bone [2,3]. No new-bone formation occurred and a strong inflammatory and foreign-body reaction was elicited. The connective-tissue bed surrounding the implant was dense. Osteoclast-like giant cells appeared

early and persisted. Resorption of these small fragments, as in the case of the large-fragment heterograft, was slow.

It is noteworthy that the small-fragment plasma-stored heterograft, which had been irradiated, produced a more severe and persistent inflammatory reaction than that elicited by the non-irradiated fragments. The reason for this accelerated and accentuated reaction is not known.

The differences in behavior of the large-fragment and small-fragment heterografts suggest that the surface area plays an important role in the production of the host-inflammatory reaction. The increased exposure of the host tissue to the foreign-bone matrix may be responsible for potentiation of the inflammatory reaction to the small-fragment and cancellous implants. It is not known whether physical stimulation of the host bed or changes in the chemical properties of the fragmented-bone substance provide the principal stimulus to reaction.

CONCLUSIONS

1. Fresh, plasma-stored, and saline-stored calf bone heterografts did not produce osteogenesis in the anterior chamber of the rat's eye. They did produce a host inflammatory and fibroblastic reaction.

2. Storage of heterogenous bone in homologous bovine plasma increased, whereas storage in saline solution decreased, the inflammatory reaction produced.

3. The inflammatory reaction was greater with the large-fragment cancellous bone heterografts than with the large-fragment cortical implants suggesting that the amount of surface area of bone implant exposed to the host tissue is significant.

4. Fragmentation of heterogenous bone also increased the inflammatory and foreign-body reaction.

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Bone Immunology

II. Comparison of Embryonic Mouse Isografts and Homografts*

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There is little doubt that the surface cells of bone survive autotransplantation better than the cells of homografts or heterografts [2,8,11,28,37,41,43,47,51]. It is also generally accepted that fresh homografts of adult bone evoke a reaction on the part of the host that is eventually associated with death of the graft [8,9,11,12,17,18,23,24,41,51,58], although recently Heslop, Zeiss, and Nisbet claimed that osteocytes may survive homografting.

In the case of embryonic or fetal-bone homografts, there is more controversy. Survival and growth of the grafts have been reported [13,26,27,29,33,34,39,48,51,61,65] and confirmed in our laboratory when eighteen-day-old embryonic rat tibiae were homotransplanted to the anterior chamber of the eye [51] and embryonic rat femora were homotransplanted to a subcutaneous vascular bed in adult Long-Evans rats [56]. However, the pattern of cartilaginous and osseous growth was abnormal—particularly growth of the diaphysis. The embryonic femora lost their pattern of organization and grew in all directions so that by the third week the grafts had the appearance of ossicles. It should be noted that in organ cultures, embryonic whole bones retain their pattern of organization [25,52].

The homograft reaction can usually be detected during the second week after transplantation [12,18,23,32,38,66] and reaches a maximum by the third week [12,18,23,38,66]. The term *homograft reaction* is used to describe a reaction characterized by vascular disturbances in the host bed, cellular infiltration (predominantly small round cells), degeneration, and progressive necrosis of the graft. The purpose of this study was to investigate embryonic-bone transplants during this early interval in an attempt to answer two questions: (1) are embryonic-bone grafts capable of evoking an immune response in the host, and (2) are embryonic-bone grafts affected by the host's response?

METHOD

Eighteen-day-old embryos from inbred mice of the Strong A strain (average period of gestation, twenty days) were used as donors. The age of the embryo was calculated from the day of fertilization, which was determined by the presence of sperm on vaginal smear. The embryos were obtained by cesarean section and the femora dissected and cleaned of soft tissue aseptically in several fresh baths of Hanks' buffered salt solution (pH 7.2 to 7.4).

Adult male Strong A and CBA inbred mice were used as hosts to eliminate the possible interference of isohistocompatible genes [21,22,31,57]. Grafts were transplanted to Strong A hosts as isografts and to CBA hosts as homografts. The host mice were sacrificed five, ten, fifteen, and twenty days after grafting. Fifteen mice of each strain were autopsied at each period. A total of sixty isografts, seventy-one homografts, and fifty-five ungrafted control femora was studied (Table I).

* This investigation was supported by Research Grant A-1339, National Institutes of Health, United States Public Health Service.

TABLE I

COMPARISON OF ISOGRAFTS AND HOMOGRAFTS OF EMBRYONIC FEMORA

Days after Transplantation	Controls * (Strong A) (55)	Isografts (Strong A Grafts to Strong A Hosts) (60)	Homografts (Strong A Grafts to CBA Hosts) (71)
0			
No. of femora	25		
Total length	3.5±0.1		
Diaphyseal length	1.3±0.1		
5			
No. of femora	7	13	15
Total length	5.5±0.1	4.0±0.2	4.0±0.2
Diaphyseal length	3.0±0.1	2.3±0.2	2.0±0.2
10			
No. of femora	10	19	18
Total length	8.0±0.2	6.0±0.5	5.0±0.3
Diaphyseal length	5.5±0.1	3.0±0.3	2.0±0.4
15			
No. of femora	6	13	19
Total length	8.5±0.2	7.0±0.5	6.0±1.0
Diaphyseal length	6.5±0.2	4.3±0.3	3.5±1.1
20			
No. of femora	7	15	19
Total length	9.0±0.5	7.0±0.7	6.0±1.2
Diaphyseal length	7.0±0.2	5.5±0.5	3.5±1.0

* Controls were not grafted but they were of comparable age.

Growth and vascularization of the grafts were visualized *in vivo*. Previously, the anterior chamber of the eye was used [40,49], but this technique has two limitations: (1) it is a privileged immunological site if vascularization is delayed [4,49] and (2) it is difficult to follow the grafts photographically. Transparent chambers previously described in the literature [1,14,42,64] proved to be unsuitable for whole-bone transplants, so a new chamber for organ transplants was developed and used in the experiments reported here; this allowed adequate space for the femur to grow for three weeks [55].

In vivo photographs of the grafts were made at regular intervals. At autopsy, India ink was injected supravitally through the ascending aorta. A few specimens were fixed in neutral formalin, dehydrated in ethyl alcohol, cleared in xylene, and mounted in Canada balsam [60]. The remaining specimens were fixed in neutral formalin, decalcified with ethylene diamine tetra-acetic acid, dehydrated in ethyl alcohol, and embedded in celloidin. Longitudinal sections, six micra thick, were cut and stained with hematoxylin and eosin.

Roentgenograms were made of selected specimens from each group before they were fixed.

RESULTS

Normal Femur

The mouse femur grows in length from 3.5 ± 0.1 millimeters in the eighteen-day old embryo to 9.0 ± 0.5 millimeters by eighteen days post partum. A zone

Fig. 1: Ungrafted control mouse femur three days post partum (× 18). The medullary canal is present.

Fig. 2: Isograft of embryonic mouse femur five days after transplantation (× 18). Note the growth of cartilage and vascularization of the diaphysis.

Fig. 3: Homograft of embryonic mouse femur five days after transplantation (× 18). There was no intimate connection between the graft and the bed, but the gross outline of the femur appears normal.

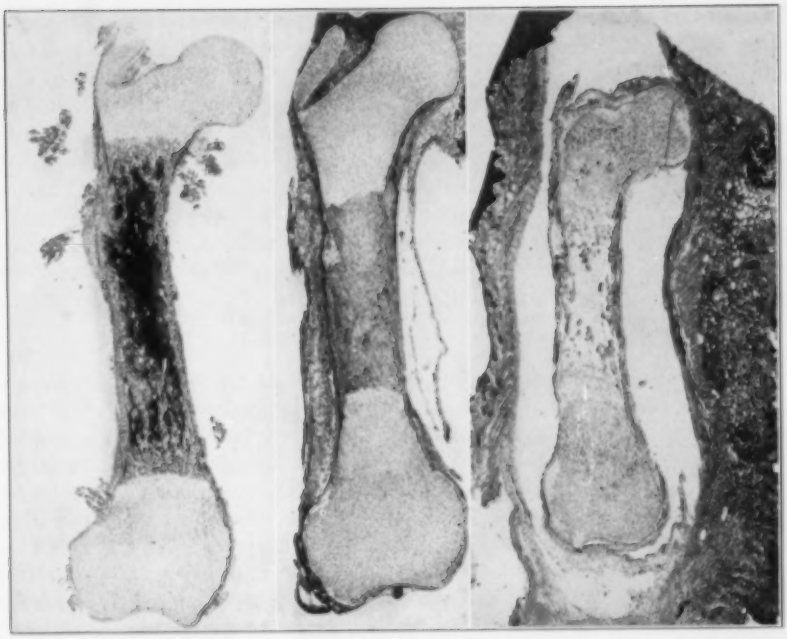

FIG. 1 FIG. 2 FIG. 3

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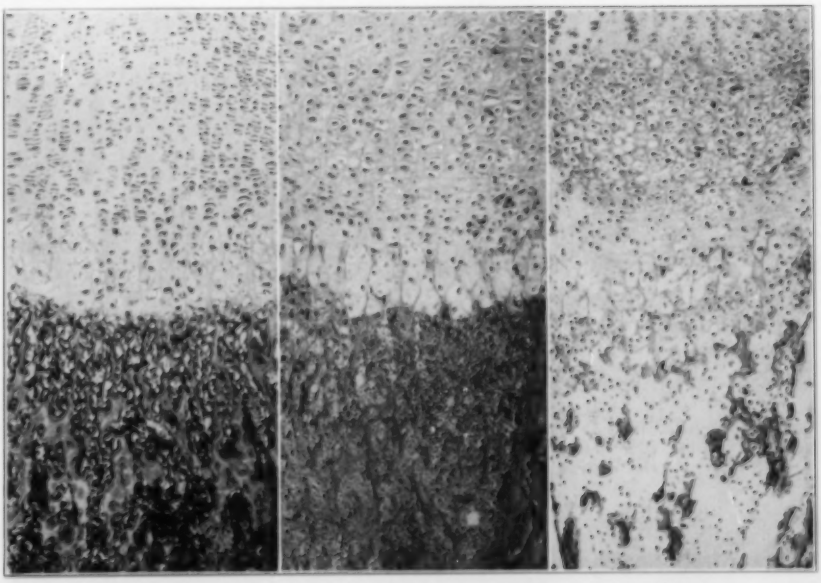

FIG. 4 FIG. 5 FIG. 6

Fig. 4: The center of the distal epiphyseal disc of the femur illustrated in Fig. 1 (× 100). Active, well organized endochondral ossification is evident.

Fig. 5: The distal epiphyseal cartilage of the femur illustrated in Fig. 2 (× 100). Regular columnar arrangement of the cartilage with intracellular calcified matrix is apparent

Fig. 6: The distal epiphyseal disc of the femur illustrated in Fig. 3 (× 100). The bone marrow has been replaced by loose undifferentiated tissue; the bone spicules are mainly acellular.

of ossification for the diaphysis is established in the eighteen-day-old embryonic femur, and this increases in length from 1.3 ± 0.1 millimeters to 7.0 ± 0.2 millimeters during the same period. There is no roentgenographic evidence of calcification of the zone of ossification until eight days post partum. Histological sections reveal well developed epiphyseal plates at either end of the diaphysis in the eighteen-day-old embryonic femur. The secondary center of ossification of the femoral condyles appears between eight and thirteen days post partum. The neck of the femur differentiates and ossifies around thirteen days post partum, but the head of the femur remains cartilaginous. Hematopoietic elements are present in the marrow of the eighteen-day-old embryo but are more fully differentiated eighteen days post partum (Figs. 1, 4, 7, 10, 14, and 17).

Isografts

In the isografts of eighteen-day-old embryonic mouse femora, there were no gross changes in appearance of the graft or the bed during the first twenty-four hours. Four days following transplantation the femur had increased in length to 4.0 ± 0.2 millimeters, and further differentiation of the cartilaginous epiphyses was apparent. The proximal end of the femur became constricted at the neck, the head rounded, and the site for the ligamentum teres femoris was defined. However, there were no apparent changes in the vascular pattern of the bed. Three to seven days after transplantation, the ossification center changed in color from white to red as it became vascularized (this was confirmed by the supravital India-ink injections described subsequently). Seven days after transplantation a large number of new capillaries appeared in the bed, and by ten days the area around the transplant was invaded with new capillaries growing in all directions. This vascular activity subsided by the thirteenth day, except for the area immediately adjacent to the graft where new connective tissue gradually covered the diaphysis. By seventeen days the condyles, head, and greater trochanter were surrounded by new capillaries and by twenty-one days the grafts had become completely buried in connective tissue except for spots in direct contact with the cover slip (Figs. 20, 21, 22, and 23).

In order to study initial vascularization, twenty randomly chosen grafts were examined daily for the typical color change of the diaphysis. It was found that the first signs of vascularization occurred between the third and seventh days after transplantation (4.4 ± 1.3 days). Supravital ink injections showed vessels penetrating the graft as early as three days after transplantation but complete vascularization of the diaphysis did not occur before five days. The femoral condyles were vascularized later, around fifteen days after transplantation (Fig. 29).

Roentgenograms did not reveal significant calcification of the grafts during the first three weeks (the normal femur showed calcification roentgenographically

Fig. 7: Ungrafted control mouse femur eight days post partum (× 15). The head, neck, greater trochanter, and distal condyles are cartilaginous.

Fig. 8: Isograft of embryonic mouse femur ten days after transplantation (× 18). Note the development of the medullary canal and ossification of the neck of the femur.

Fig. 9: Homograft of embryonic mouse femur ten days after transplantation (× 18). Host vessels have invaded the distal condyles and neck of the femur with progressive vascularization throughout the diaphysis.

Fig. 10: The center of the distal epiphyseal cartilage of the femur illustrated in Fig. 7 (× 115). Organized endochondral ossification is evident.

Fig. 11: The central portion of the distal epiphyseal cartilage illustrated in Fig. 8 (× 115) reveals active endochondral ossification.

Fig. 12: The central portion of the distal metaphyseal region of the femur illustrated in Fig. 9 (× 115). Note the area of host invasion and cartilage resorption between the remnants of the original epiphyseal cartilage. Some new-bone formation has occurred, but without specific shape or orientation.

Fig. 13: The central portion of the distal epiphyseal cartilage of an embryonic mouse homograft ten days after transplantation (× 115). In the instance illustrated, the cartilage cells of the epiphyseal disc region were more regularly arranged than those in the other animals in this group.

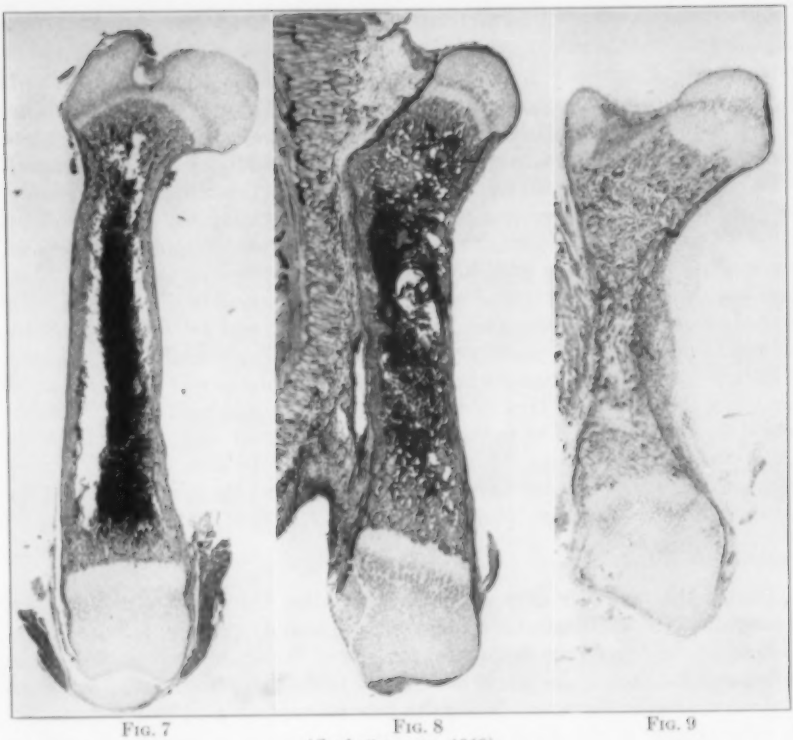

FIG. 7 FIG. 8 FIG. 9

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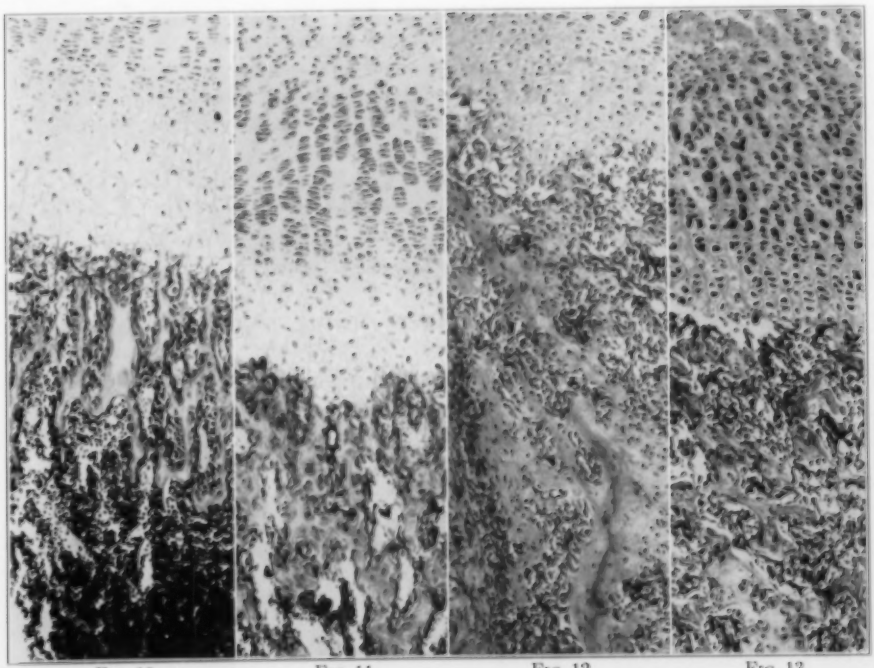

FIG. 10 FIG. 11 FIG. 12 FIG. 13

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by thirteen days post partum, as noted previously). Histological sections of the isologous femur at five days revealed no change compared with the embryonic eighteen-day-old normal femur, except in the epiphyseal plate where the cells assumed a columnar arrangement. The shaft showed some new-bone formation, but the original bone appeared acellular. Between the trabeculae, the marrow spaces were filled with immature hematopoietic cells in various stages of differentiation. Ten days after grafting, the medullary cavity had begun to develop. New-bone formation was evident beneath the cambium layer of the periosteum and in the metaphyseal region. There was no clear-cut differentiation between the periosteal layers of the graft and the connective tissue of the host bed. By fifteen days, a secondary center of ossification had appeared in the condyles. The remaining cartilage cells were mainly hypertrophic except for the zone of proliferation of the epiphyseal plate and the articular cartilage. Additional periosteal and enchondral-bone formation was evident. The diaphysis was tubular but the bone was primarily cancellous. Trabeculae in the metaphyseal zone were surrounded by osteoblasts. The medullary cavity was filled with myeloid cells in various stages of maturation. Marrow cells could also be seen in the secondary center of ossification. Twenty days after transplantation the graft resembled the normal fifteen-day-old femur histologically (Figs. 2, 5, 8, 11, 15, and 18).

Homografts

During the first four days after transplantation the homografts resembled the isografts. The cartilaginous epiphyses continued to grow and differentiate. The head of the femur was round and the site of the ligamentum teres femoris was defined; the neck of the femur had started to differentiate. In some instances initial vascularization occurred during this interval accompanied by the characteristic color change of the diaphysis. The vascular pattern of the bed showed no change except for dilatation of a few vessels. The first major difference between the isograft and homograft occurred around seven days when the bed became covered with loose fibrous connective tissue that caused a cloudy appearance in the chamber. By ten days, a few new capillaries were seen in the region between the femoral condyles and the metaphysis. New capillaries also appeared around the diaphysis. The cloudiness previously described disappeared in the areas where new vessels appeared. By thirteen days the cloudiness had decreased still further coincident with additional vascularization. By seventeen days new vessels surrounded the graft and by twenty-one days most of the diaphysis as well as parts of the cartilaginous epiphyses were covered by connective tissue. The area of the bed not invaded by new capillaries remained cloudy (Figs. 24, 25, 26, and 27.)

Initial vascularization of the diaphysis occurred between the third and seventh days after transplantation (average, 4.5 ± 1.1 days). Supravital India-ink injections revealed that five days after transplantation, blood vessels had

Fig. 14: Ungrafted control mouse femur thirteen days post partum (× 13). Note the ossification of the neck and establishment of the secondary center of ossification in the distal condyles.

Fig. 15: Isograft of an embryonic mouse femur fifteen days after transplantation (× 13). A secondary center of ossification has been established in the distal epiphysis.

Fig. 16: Embryonic mouse femur fifteen days after homotransplantation (× 13). The general contour of the femur is preserved, although the diaphysis is composed of small bone trabeculae. Endochondral ossification has been disrupted (compare with Fig. 13).

Fig. 17: The center of the distal epiphyseal disc of the femur illustrated in Fig. 14 (× 100). Active endochondral ossification is evident.

Fig. 18: The central portion of the distal epiphyseal cartilage illustrated in Fig. 15 (× 100) shows a decrease in activity of endochondral ossification.

Fig. 19: The central portion of the distal epiphyseal cartilage of the femur illustrated in Fig. 16 (× 100). Endochondral ossification is disorganized and cartilage rests are present in the diaphysis.

FIG. 14

FIG. 15

FIG. 16

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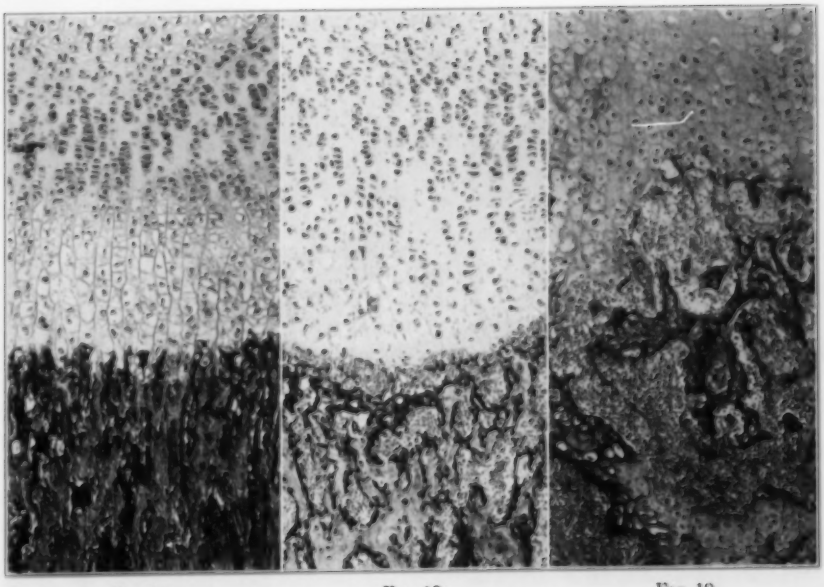

FIG. 17

FIG. 18

FIG. 19

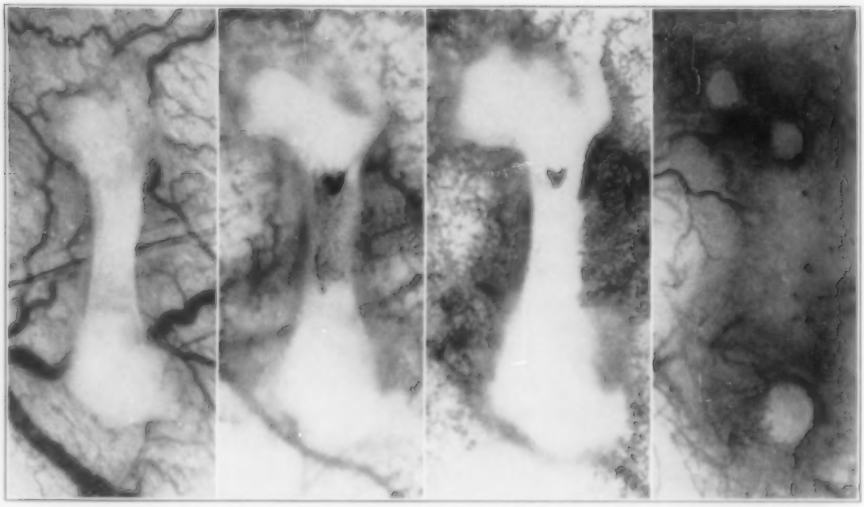

FIG. 20 FIG. 21 FIG. 22 FIG. 23

Fig. 20: Isograft of embryonic mouse femur one day after transplantation (× 14). A small nerve with its blood vessel crosses the field under the white diaphysis.

Fig. 21: The same femur illustrated in Fig. 20 six days later (× 14). The diaphysis is dark due to vascularization. The neck of the femur has developed. Hyperemia is evident around the diaphysis.

Fig. 22: The same femur illustrated in Fig. 20 twelve days later (× 14). New connective tissue and capillaries are beginning to surround the diaphysis. Hyperemia is persistent.

Fig. 23: The same femur illustrated in Fig. 20 eighteen days later (× 14). The whole femur has been covered by connective tissue except for three cartilage areas in direct contact with the cover slip. Hyperemia has subsided around the diaphysis.

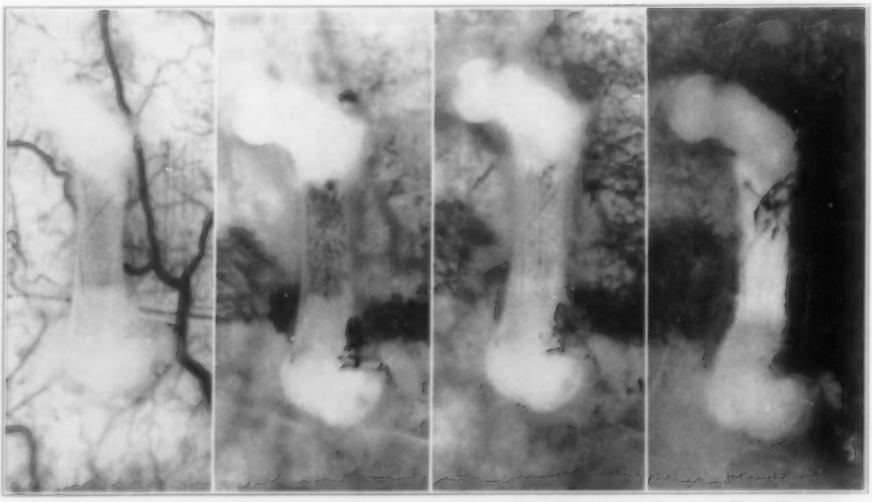

FIG. 24 FIG. 25 FIG. 26 FIG. 27

Fig. 24: Embryonic mouse femur homograft one day after transplantation to a transparent chamber in an adult mouse (× 14). A small nerve with its blood vessels crosses the field under the distal condyles.

Fig. 25: The same femur illustrated in Fig. 24 six days later (× 14). The diaphysis appears dark due to vascularization. The bed is covered by loose connective tissue and appears cloudy. Hyperemia is evident around the diaphysis.

Fig. 26: The same femur illustrated in Fig. 24 twelve days later. The area of capillary proliferation is clear, whereas the rest of the bed remains cloudy (× 14). Hyperemia has increased around the graft.

Fig. 27: The same femur illustrated in Fig. 24 eighteen days later. There are new capillaries and connective tissue surrounding the graft (× 14). Hyperemia is still evident.

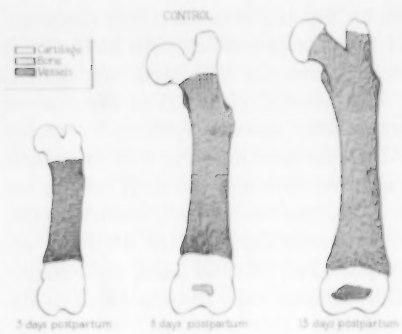

FIG. 28

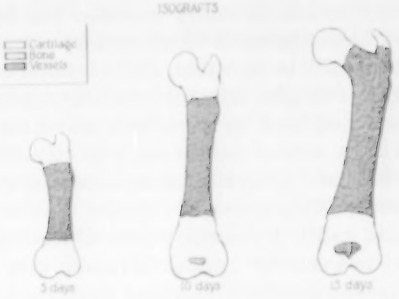

FIG. 29

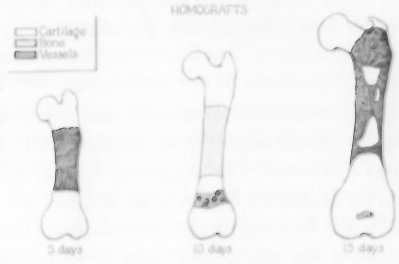

FIG. 30

Fig. 28: Distribution of cartilage, bone, and blood vessels in ungrafted control mouse femora.

Fig. 29: Diagram showing the distribution of bone, cartilage, and blood vessels in isografts at different periods after transplantation.

Fig. 30: Diagram showing the distribution of bone, cartilage, and blood vessels in homografts at different periods after transplantation.

usually penetrated the periphery of the diaphysis, but this initial vascular supply did not persist. Additional new vessels usually penetrated the distal cartilage in the area between the condyles and the metaphysis about ten days after transplantation. The diaphysis became avascular after failure of the first vascularization, but by fifteen days it became revascularized in some cases. In contrast to the isografts, vascularization of the secondary center of ossification was delayed until fifteen days after transplantation (Fig. 30).

Roentgenograms showed no evidence of calcification during the first twenty days after grafting.

As mentioned earlier, the five-day homografts appeared similar to the isografts when examined grossly. However, histological differences were apparent. In the homografts, the marrow was replaced by loose undifferentiated connective tissue. The cartilage continued to grow and most of the chondrocytes appeared normal, but the hypertrophic zone of the epiphyseal cartilage was increased in width, apparently because of failure of ossification. The diaphysis showed very limited new-bone formation. The majority of the bone present was acellular and the matrix basophilic. By ten days, new vessels from the host had invaded the epiphyseal cartilage of the condyles with erosion of the cartilage. Occasional chondroclasts were seen in the region of these vessels. This secondary vascular invasion and erosion was located between the cartilaginous condyles and the old epiphyseal plate which remained as cartilaginous rests in the diaphysis. The new-bone trabeculae showed no specific pattern of orientation. This invasion, resorption of cartilage, and new-bone formation was localized to the hypertrophic zone of the cartilaginous epiphysis with only one exception where the process extended throughout the shaft. Several cell types could be distinguished in the eroded areas including chondroclasts, osteoclasts, fibrocytes, erythrocytes, and lymphocytes. Lymphocytes were also present in the tissues surrounding the graft. By fifteen days, new periosteal-bone formation had occurred around the shaft, but this

appeared to be mainly acellular. The diaphysis was not intact but was composed of bone fragments which were so arranged that the general contour of the graft could still be identified. Endochondral ossification was abnormal and cartilaginous rests extended into the medullary cavity. The myeloid elements of the marrow were replaced by fibroblasts and loose granulation tissue. Erythrocytes within clearly defined vessels and also extravascular were seen inside as well as outside the graft. Lymphocytes were seen in the marrow spaces of the graft and in the surrounding tissues. By twenty days most of the trabeculae were acellular, thin, and small. A secondary zone of ossification was established in the condyles, accompanied by cellular invasion with lymphocytes, plasma cells, and multinucleated cells. Fibroblasts and loose undifferentiated cells predominated in the medullary canal (Figs. 3, 6, 9, 12, 13, 16, and 19).

For purposes of comparison, the foregoing results have been summarized in Table I and Figures 28, 29, and 30.

DISCUSSION

Murray and Huxley [50] and Hancox [33,34] transplanted embryonic chick bone to the chorioallantoic membrane with subsequent new-bone formation. Huggins and Blocksom [29] homografted immature rat tails, obtained within six hours after birth, to adult hosts. The bone grew and differentiated in a normal manner. Willis [65] homografted embryonic rat limbs to the brains of adult hosts, where most of the grafts developed irregular shapes. Nevertheless, some grew and differentiated. Steinman [61] transplanted eighteen-day-old embryonic rabbit bone into bone defects in adult rabbits and found cartilaginous callus which was later replaced by endochondral ossification. Gordon and Warren [29] transplanted diced rabbit fetal cartilage to bone defects in adult hosts and observed limited growth. Ray and associates [51] transplanted embryonic rat tibiae to the anterior chamber of the eye of adult rats and found considerable growth and differentiation. Felts [26,27] homografted immature mouse humeri subcutaneously with the same results. Crouse [16] transplanted rat limb buds to the brains of adult hosts and found considerable growth and differentiation. The results obtained in this experiment differ from the foregoing studies, but this may be because of a greater degree of genetic disparity between the donors and recipients, or because the subcutaneous bed used for the grafts was not immunologically privileged, or both. With regard to the first possibility, the homograft reaction is not an all-or-none phenomenon. Variations in response depend on genetic similarities or differences between the donor and the recipient. Several excellent reviews have been devoted to the genetic aspects of tissue transplantation [7,30,36,46,59]. Concerning the second possibility, the anterior chamber of the eye has been considered to be immunologically privileged as long as the graft remains avascular [49]. However, if the anterior chamber becomes vascularized before or during grafting, the subsequent behavior of the graft will be the same as in other vascular sites [4]. The brain is regarded as another privileged site, possibly because of the paucity of lymphoid tissue [10,49].

The results of this experiment are in agreement with recent reports on embryonic-tissue transplants in adult mice. Haškova [35] homografted eight, ten, and twelve-day embryonic limbs and found that the maximum survival time was sixteen to eighteen days, except for cartilage, which in most cases remained undamaged up to twenty-five days. Chalmers and Ray [13] found similar results following transplantation of eighteen-day-old embryonic femora to the spleen in adult mice. Billingham and associates [5] demonstrated that mice embryos contain transplantation antigens that provoke an immune reaction in adult hosts. They

injected adult mice with as few as five million cells from twelve-day embryos three days before grafting. An accelerated homograft reaction was observed (second-set phenomenon).

Immunologically speaking, whole-bone grafts are composed of three main tissues: marrow, bone, and cartilage. These tissues show different behaviors and for the sake of clarity will be discussed separately.

The first differences between the isografts and homografts were detected in the bone marrow. Primitive marrow, present in the embryonic graft, differentiated in the isografts, but was replaced in the homografts by loose undifferentiated connective tissue that persisted for ten to fifteen days. Vascular invasion of the cartilage in the homografts was accompanied by myeloid as well as fibrous connective-tissue cells. The appearance of the latter in the marrow was a constant finding in the homografts.

For the first few days the zone of ossification in both the isografts and homografts looked the same. After vascularization endochondral and periosteal-bone formation were seen in the isografts, but the bone formation in these grafts was not as great as in the normal femora. In the homografts, on the other hand, very limited bone formation occurred subsequent to vascularization and although a few new trabeculae appeared, the origin of this bone was obscure. It may have been produced by proliferation of graft cells or by metaplasia of the invading host cells (further studies will have to be carried out to answer this question). If the new bone was derived from the cells of the graft, embryonic-bone homografts may be credited for supplying osteogenic cells. On the other hand, if the observed new bone was derived by metaplasia of the host cells, embryonic-bone homografts may be credited for supplying an osteogenic inductor.

Cartilage behaved differently than either bone marrow or bone. Although cartilage cells may survive and even grow and multiply as homografts, this does not mean that cartilage is invulnerable to the homograft reaction. Loss of contour of the distal femoral condyles was noticed after twenty days. Vascularization of the secondary center of ossification of the epiphysis was delayed in the homografts. The epiphyseal disc was also affected by the homograft reaction. Five days after transplantation the four zones were present but the intracolumnar matrix was reduced in the homografts. At ten days, the differences were more pronounced. The isografts appeared normal, whereas the epiphyseal zones of the homografts were disrupted by vascular invasion and irregular erosion of the cartilage. At fifteen days the activity of the diaphyseal cartilage began to decrease in the isograft. In the homograft the process was disrupted. Large remnants of epiphyseal cartilage were seen to persist in the diaphysis. However, it would appear that cartilage is less affected by the homograft reaction and at a later date than bone. Craigmyle [15] demonstrated the antigenicity of cartilage by an increase in size of the regional lymph nodes after repeated cartilage homografting. Ring [53,54] found that epiphyseal-cartilage homografts failed to grow in length normally and the homograft cartilage cells metabolized sulphur at a higher rate.

The initial time for vascularization of isografts and homografts was approximately the same (no significant difference was found between the two groups when the standard t test was applied). However, the initial vascular pattern of the isografts persisted, whereas this was altered in the homografts. Around ten days the host vessels reinvaded the cartilage and later extended through the diaphysis. These host vessels remained functioning thereafter. Circulatory disturbances in homografts have been described by several investigators [32,43,44,62,66]. The question arises whether marrow and bone cells respond directly to antibodies of the host or whether the changes are due to alterations in circulation which in turn are

the result of an immune reaction. Recently Knake [45] investigated vascularization of homografts of liver, spleen, thyroid, and kidney and concluded that the cells of the graft are affected directly by the immune response. Improving the vascular supply did not alter the reaction appreciably.

In this experiment intimate connection between the homograft and the surrounding tissues was not established. Round cells were seen inside as well as surrounding the homografts for as long as twenty days after grafting. Isografts, on the other hand, were intimately connected with the host.

The foregoing sequence of events occurs following the initial experience of a host with a bone homograft from a specific donor. This reaction can be intensified by presensitizing the host with cells from the donor strain [5,12] (second-set phenomenon). A group of eight adult CBA male mice were given four equal injections of ten million spleen cells from the Strong A strain one week apart. Eighteen-day embryonic femora of the Strong A strain were then transplanted to a transparent chamber one week after the last injection. The grafts remained avascular during the ensuing ten days even though the surrounding host bed became hypermic (but not cloudy). Histologically, the marrow of the grafts was replaced by undifferentiated cells. There was no evidence of new-bone formation. The lymphocytic-fibroblastic reaction was confined to the host bed with eventual isolation of the grafts by formation of fibrous-tissue capsules.

The study carried out by Chalmers and Ray [13], using strains of mice similar to those used in this study, suggested that the behavior of embryonic-bone homografts is similar to adult-bone homografts. This experiment confirms the fact that embryonic-mouse bone possesses transplantation antigens which evoke an immune response in the adult host. However, this reaction is probably not identical to that seen in response to adult-bone homografts. In a previous study of embryonic-rat bone transplanted to the anterior chamber of the eye of adult hosts, the bone proliferated and grew [51], but when adult bone was homografted very limited new bone appeared, and the graft eventually underwent necrosis.

The possibility that there is a difference between the antigenicity of embryonic and adult bone is supported by two theoretical points. First, there is no reason to believe that transplantation antigens of embryonic tissues persist quantitatively or qualitatively to adulthood. Some new antigens appear, some are lost, and still others modified (see the recent reviews of Edds [20] and Ebert [19]). Second, adult bone-marrow homografts are capable of reacting against the hosts in contrast to embryonic bone-marrow homografts [3]. Since adult cancellous bone contains bone marrow, one might anticipate that such grafts could develop a graft versus host immune reaction in addition to the classic host versus graft reaction.

SUMMARY AND CONCLUSION

Eighteen-day-old embryonic femora of Strong A mice were transplanted subcutaneously to adult male mice of Strong A strain as isografts and the CBA strain as homografts. Transplants were observed grossly *in vivo* for three weeks. Host mice were sacrificed at intervals from five to twenty days after transplantation. Vascular, roentgenographic, and histological studies were carried out. A total of 186 specimens was examined of which sixty were isografts, seventy-one homografts, and fifty-five ungrafted controls.

Both isografts and homografts became vascularized between the fourth and fifth day after transplantation. Subsequently, the vascular supply increased in the isografts but decreased in the homografts. The host bed around the isografts remained clear throughout and became hyperemic then returned to normal, whereas the host bed around the homografts was clear, then cloudy, then hyperemic thereafter.

Histologically, endochondral and intramembranous ossification appeared normal in the isografts (although lesser in degree than the controls). The secondary center of ossification for the femoral condyles appeared at the normal time, but later endochondral ossification decreased until it became inactive. In the homografts the marrow was replaced by loose undifferentiated cells, the epiphyseal disc became disorganized, endochondral ossification was disrupted with cartilaginous rests persisting in the diaphysis, and vascularization of the secondary center of ossification of the condyles was delayed. Infiltration with small round cells was noticeable both inside the grafts, as well as in the host beds surrounding them.

From these results it is concluded that embryonic mouse femur from one inbred strain possesses transplantation antigens that can invoke a tissue immune response in adult mice of a different inbred strain.

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DISCUSSION

Suction Drainage of Orthopaedic Wounds

(*Continued from page 946*)

pulse rate increases and his coronary arteries contract. Only when he takes a blood count and finds that the leukocyte count has not gone up with the fever, does he begin to relax. Nevertheless, he does not know and I do not know what the secondary rise in temperature means. What causes it? Where does it come from? What has happened on this fourth or fifth day? Can our authors tell me what is this phenomenon which they are apparently eliminating?

For some years I have felt that this secondary rise in temperature must be related to some sudden change in the hematoma which normally occurs in large incisions—such as sudden liquefaction and absorption—since a secondary rise seems to occur consistently in the absence of any infection. As I observed the temperature curves shown by Dr. Waugh and Dr. Stinchfield, I noted that the second rise in temperature, which is ordinarily seen on the fourth or fifth postoperative day, seems to have been eliminated.

Dr. Stinchfield (closing): I think that on our service, the greatest single factor producing infection is the hematoma. If we can eliminate hematomata from wounds, I believe the infection rate will decrease and functional results will improve. There were seventeen positive cultures in the series, yet only one produced a clinical infection. I wonder how often we have bacteria in a wound, which the natural defenses of the body can handle, in the absence of the additional insult produced by a hematoma. The lack of infection in sixteen of these wounds, I think, can be credited to the resistance of the body, which did not have to contend with the extra burden of a hematoma.

As far as the postoperative temperature is concerned, we expected there would be more of a change than there actually was. In none of these patients, however, did the temperature go up again after removal of the catheter.

What do we learn from this? We learn that if good surgical principles are followed, the convalescence is made easier. I think that the catheters should be placed deeply. At first, we were hesitant to insert a drain down to a prosthesis, to a mold, or to a spine fusion—we now insist that this be done. We feel that the loss of an additional 100 to 200 cubic centimeters of blood is a small price to pay as we are convinced that the body will take care of many bacteria if it does not have the added insult of a hematoma.

An Experimental Study of Joint Stiffness*

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Joint contractures result from prolonged immobilization. The nature of the physical changes in connective tissues which cause these contractures is not understood. This paper presents a study of changes in water and total hexosamine content of the synovial membrane, tendon, capsule, and ligamentous structures of dogs' knees in which contractures have developed after various periods of immobilization. A similar previous study of articular cartilage after joint immobilization showed expansion of the extracellular water compartment and loss of acid hydrolyzable sulphate [1]. Slack [29] demonstrated decreased sulphate uptake in the whole minced denervated rat limb. Nearly all of the ester sulphate in cartilage is part of the chondroitin sulphate molecule. Hence, the changes in the acid hydrolyzable sulphate and the decreased sulphate uptake associated with immobilization suggest alterations in polysaccharide metabolism. Changes in the content of polysaccharide and of water may occur in other periarticular tissues during immobilization and may be responsible for the changes in the physical properties of joint structures that cause contractures. The studies reported here were undertaken to test this hypothesis.

It should be made clear at the outset that in this paper the term *joint stiffness* refers to that process which occurs in a normal joint which has been restricted from motion. The loss of joint motion that occurs in diseased and traumatized joints, in which scar has formed, is not considered.

PROCEDURES AND METHODS

Fifty mongrel dogs were used in this study. One hind extremity was immobilized by means of internal fixation. External immobilization by plaster or resin dressings was unsatisfactory for purposes of this study because pressure sores developed. For short-term experiments, a threaded wire, one-eighth of an inch in diameter, was drilled through the mid-shaft of the tibia into the proximal portion of the femur, using sterile technique. The course of the threaded wire was planned in such a way that the wire did not penetrate the skin behind the knee (Fig. 1). In this manner infections incident to a chronic open wound were avoided. A hexagonal nut was run up the thread of the wire against the tibia. The wire was cut off below the skin and the threads roughened to prevent the nut from backing off. This procedure could be done through a one-centimeter incision over the tibia. It was not found necessary in short-term experiments to place a hexagonal nut over the threaded wire at the opposite end where the wire penetrated the femur. For long-term experiments, a double strand of malleable, 20-gauge, stainless-steel wire was wrapped around the proximal portion of the femur and the distal portion of the tibia. The incisions for inserting this wire were placed in such a way that the skin of the calf could be sewn to the skin of the thigh to enclose the wire.

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Animals in which infections developed were discarded from the study, and animals in which the wire broke were discarded unless a contracture had developed in the joint. Tissue from the latter animals was analyzed, but it was not included in the time study.

Because of age and species differences which could not be controlled, it was necessary to use individual controls for each animal: tissue from the experimental leg was compared with identical tissue from the normal leg in each animal. Tissues which were analyzed included the quadriceps and patellar tendons, the synovial membrane and capsule, the meniscus, the fascia lata, and the skin from the anterior portion of the thigh and the leg. The samples were removed immediately after the animal was killed with a large dose of pentobarbital. The synovial

FIG. 1

Roentgenogram of the hind limb of a dog illustrates the method of immobilization used for most of the animals in this experiment. An eighth-inch threaded wire was drilled through the anterior part of the tibia, through the soft tissues behind the knee, and into the proximal portion of the femur. The entire length of the threaded wire was buried beneath the skin.

membrane and capsule were removed together from the region adjacent to the patella on the anteromedial and anterolateral aspect of the knee (Fig. 2). The synovial membrane and capsule could not be easily separated by dissection—they were studied as a unit. The meniscus was studied as an example of fibrocartilage, a tissue whose histological composition is mid-way between that of hyaline cartilage and that of fascia or tendon. These tissues were analyzed after intervals of one, one and one-half, and two weeks of immobilization, and then every two weeks until twelve weeks. The joints of six normal animals were compared to determine the magnitude of differences between samples of normal right and left legs of the same animal.

After sacrifice, the fresh wet tissues were weighed as soon as they were dissected free from the knee joint. They were then dried in a vacuum oven at 78 degrees centigrade until the weight was constant on successive weighings. The neutral fat was extracted with several changes of ether, and the tissue was dried again until the weight was constant. The fat content was calculated, and the estimation of water content was made on the basis of fat-free wet weight and fat-free dry weight. The tissues were then ground in a Wiley mill.

Hexosamine determinations were performed on tendon and tissue from the synovial membrane and capsule. The determinations were based on the Elson-Morgan reaction according to the method of Boas. The ion-exchange resin used

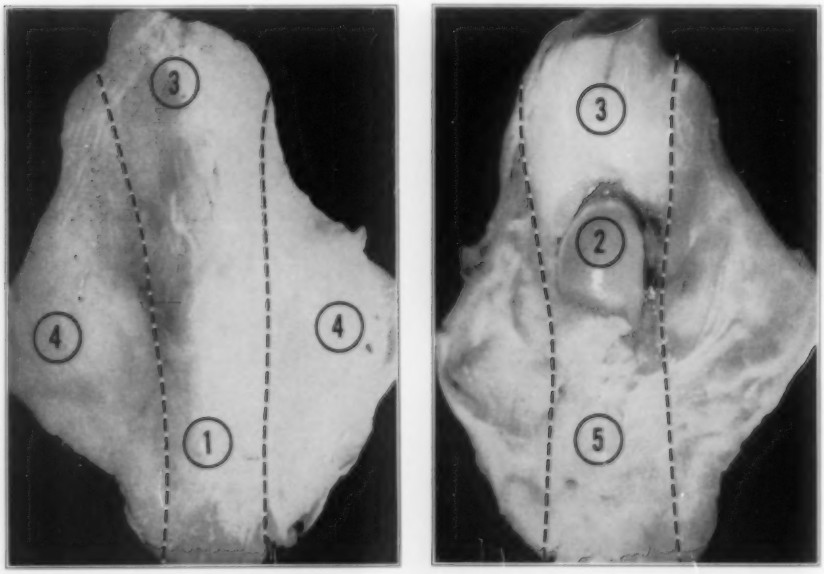

FIG. 2

Photographs of a dissected specimen: *1*, patellar tendon; *2*, patella; *3*, quadriceps tendon; *4*, capsule and underlying synovial membrane; and *5*, infrapatellar fat pad.

was Dowex-50, 200-400 mesh *. The weighed samples of dried tissue were hydrolized in three milliliters of 3N hydrochloric acid for six hours. This procedure had previously been demonstrated in this laboratory to produce the maximum hexosamine values for dog tendon and capsule. The results listed in this paper are average values obtained on at least three aliquots.

A few normal specimens of tendon and capsule were checked for the proportion of glucosamine and galactosamine according to the method of Roseman and Daffner, which depends on conversion of glucosamine and galactosamine to the N-acetyl derivatives by treatment with acetic anhydride. The derivatives thus formed are determined colorimetrically by the Elson-Morgan reaction. Whereas the glucosamine and galactosamine molecules give the same colorimetric optical density by the reaction, their N-acetyl derivatives do not. N-acetyl glucosamine gives approximately three times as much color as N-acetyl galactosamine. When the total hexosamine and the slope of the standard curve for N-acetyl glucosamine

* California Biochemicals.

and N-acetyl galactosamine are known, the proportion of glucosamine and galactosamine can be determined algebraically.

Hydroxyproline was determined by the Neuman-Logan method. The tissue was hydrolyzed in a sealed tube in an oven at 138 degrees centigrade for three hours, as suggested by Levene and Gross. The general modifications of Miyada and Tappel were followed. At 555 micra, the color intensity was relatively constant between thirty and ninety minutes. Therefore, readings were made at this wave length.

In order to attempt a rough classification of the polysaccharides present in dog connective tissues, polysaccharide extractions were performed on a number of normal specimens. The general technique of Bollet was followed in which tissue is dehydrated with repeated washes of acetone and then ether, lyophilized, and finally ground in a Wiley mill. This ground tissue was then homogenized in 0.5N sodium hydroxide in a blender for forty minutes in a cold room, with pauses each ten minutes to allow the mixture to cool in an ice bath. The mixture was neutralized with acetic acid and the protein was then precipitated with 17 per cent perchloric acid. Aliquots of the supernatant were taken and dialyzed against running tap water to remove salts. The dialysate was lyophilized. The residue, which represented partially purified mucopolysaccharide, was dissolved in one milliliter of water. Fifty lambda were spotted on Whatman No. 1 filter paper in ascending chromatography systems, as described by Kerby. The solvents were ethanol-phosphate and propanol-phosphate; the staining procedures with toluidine blue were those of Leitner and Kerby. Standards were heparin, hyaluronic acid, and chondroitin sulphate *.

RESULTS

The results of estimation of water concentration are listed in Tables I through V. The response to immobilization of the various types of connective tissue tested was not uniform. Capsule and synovial membrane gradually lost water content up until two weeks. From that point on, the water content remained fairly constant at an average of 2 per cent below that of the control limb. Between the two-week and twelve-week time periods, experimental values are statistically different from the control values by the t test. A certain amount of scatter was evident. In each case the change from the control values represents the comparison of the experimental limb of the animal to its own mobile contralateral limb. Tendon was observed to develop a transitory increase in water concentration. The peak occurred at the earliest time period studied—one week. From that point on, the water content fell gradually. An analysis of variance confirms what is apparent from Table II, namely, that a distinct downward trend is present. The water content of the meniscus did not vary over the period of observation. Skin and fascia demonstrated dehydration under the influence of immobility. Between the second and twelfth week no trends were present. In that respect, the behavior of these tissues was similar to capsule and synovial membrane.

Tendon and synovial membrane and capsule (Tables VI and VII) were chosen for hexosamine analysis as structures which are intimately related to joint mobility. In the synovial membrane and capsule, the hexosamine concentration of the experimental limb decreased rapidly to about 10 per cent less than that of the control side. This alteration remained relatively constant between two and twelve weeks. The difference is statistically significant by the t test. There were no significant differences between the findings at different time intervals between the

* Nutritional Biochemicals, Inc.

TABLE I

WATER CONTENT OF SYNOVIAL MEMBRANE AND CAPSULE

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Water Content		Difference*	Average
			Control (*Per cent*)	Experimental (*Per cent*)		
M-34	L	1	72.6	71.5	−1.1	
M-35	R	1	73.0	73.0	0	
M-40	L	1	70.6	71.7	+1.1	
M-41	R	1	70.2	69.8	−0.4	−0.05
M-42	L	1	70.3	72.5	+2.2	
M-43	R	1	74.3	72.2	−2.1	
M-37	R	1½	72.9	73.9	+1.0	
M-38	L	1½	71.2	68.9	−2.3	−0.77
M-39	R	1½	71.1	70.1	−1.0	
M-31	L	2	73.8	72.3	−1.5	
M-32	L	2	71.8	68.4	−3.4	−4.00
M-33	L	2	73.2	66.1	−7.1	
M-22	L	4	73.8	68.2	−5.6	
M-26	L	4	72.2	71.0	−1.2	−2.35
M-27	L	4	72.6	72.2	−0.4	
M-10	L	4	70.6	68.4	−2.2	
M-8	L	6	72.4	69.6	−2.8	
M-28	L	6	76.3	74.8	−1.5	
M-29	L	6	72.5	69.9	−2.6	−1.76
M-30	L	6	73.1	71.6	−1.5	
M-53	R	6	70.1	69.7	−0.4	
M-17	L	8	73.1	68.8	−4.3	
M-54	L	8	73.1	69.1	−4.0	−3.33
M-56	L	8	68.2	68.2	−1.7	
M-6	L	10	77.8	69.1	−8.7	
M-48	L	10	70.6	70.4	−0.2	−2.90
M-50	L	10	71.0	69.0	−2.0	
M-15	R	10	70.3	69.6	−0.7	
M-3	L	12	71.8	71.1	−0.7	
M-4	L	12	73.6	69.7	−3.9	−1.97
M-11	L	12	72.6	71.3	−1.3	

* Utilizing the t test, the difference between control and experimental sides over the interval one to twelve weeks is significant with $P < 0.01$.

second to twelfth week. Tendon values for hexosamine, on the other hand, showed an initial increase in hexosamine content at one week, then a gradual decrease in the amount of hexosamine by four weeks to about the same level below the control, as was shown by synovial membrane and capsule. There were no significant differences between the groups according to time between the fourth and twelfth weeks.

Hydroxyproline determinations were performed as a measure of the total collagen. Spot checks were made at different time intervals to determine whether there might be significant differences in the collagen mass of the experimental and control sides. As shown by the figures in Table VIII, no significant change occurred. The manner in which hexosamine values are expressed is relevant. Frequently in studies of aging, hexosamine is expressed in terms of mass of collagen [10]. There was no apparent advantage to that manner of expression in this experiment; therefore, hexosamine results are expressed in terms of unit mass of dry tissue.

TABLE II

WATER CONTENT OF TENDON

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Water Content Control (*Per cent*)	Water Content Experimental (*Per cent*)	Difference*	Average
M-34	L	1	68.0	69.0	+1.0	
M-35	R	1	69.7	70.2	+0.5	
M-40	L	1	68.1	68.2	+0.1	+0.60
M-41	R	1	67.6	67.0	−0.6	
M-42	L	1	66.2	67.4	+1.2	
M-43	R	1	68.4	69.8	+1.4	
M-37	R	1½	70.6	71.8	+1.2	
M-38	L	1½	67.8	67.8	0	−0.27
M-39	R	1½	70.3	68.3	−2.0	
M-31	L	2	69.0	68.5	−0.5	
M-32	L	2	66.9	66.7	−0.2	−0.35
M-22	L	4	67.8	66.8	−1.0	
M-26	L	4	70.1	69.1	−1.0	−0.95
M-27	L	4	70.0	70.2	+0.2	
M-10	L	4	67.4	65.4	−2.0	
M-8	L	6	68.4	66.6	−1.8	
M-28	L	6	71.4	68.8	−2.6	
M-29	L	6	68.2	67.8	−0.4	
M-30	L	6	69.8	69.2	−0.6	−1.24
M-53	R	6	69.5	68.7	−0.8	
M-17	L	8	68.3	66.3	−2.0	
M-54	L	8	71.9	65.8	−6.1	−4.40
M-56	L	8	70.1	65.0	−5.1	
M-6	L	10	68.4	67.4	−1.0	
M-48	L	10	71.0	69.5	−1.5	
M-50	L	10	69.1	68.5	−0.6	−1.48
M-51	R	10	70.5	67.7	−2.8	
M-3	L	12	70.4	67.9	−2.5	
M-4	L	12	70.1	67.9	−2.2	−2.33
M-11	L	12	68.3	66.0	−2.3	

* Over the interval four to twelve weeks the difference between control and experimental groups is significant by the t test with $P < 0.01$.

In a certain number of animals the fixation wires broke; these animals were not included in the time study. In some of them contractures had developed. The total hexosamine and water changes, which occurred in the joints of these animals, were of the same general direction and magnitude as those previously described.

The concentrations of water and hexosamine in the connective tissue of the right and left limbs of six normal dogs were studied: the difference between limbs was not statistically significant by the t test in any of the tissues. There was a trend toward more water on the left side in the few specimens of synovial membrane and capsule. This variation would probably be reduced if a larger sample were used; but, since the direction was opposite to the experimental results, the matter was not pursued further. The concentration of glucosamine and galactosamine in pooled normal dog tendon is noted in Table IX.

DISCUSSION

It is clear that water and acid mucopolysaccharide concentration and dis-

TABLE III

WATER CONTENT OF MENISCUS

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Water Content Control (*Per cent*)	Water Content Experimental (*Per cent*)	Difference*	Average
M-34	L	1	68.9	69.7	+0.8	
M-35	R	1	70.0	69.9	−0.1	
M-40	L	1	68.7	68.9	+0.2	+0.33
M-41	R	1	69.5	69.6	+0.1	
M-42	L	1	70.2	70.7	+0.5	
M-43	R	1	69.6	70.2	+0.5	
M-37	R	1½	68.1	71.9	+3.8	
M-38	L	1½	68.4	68.4	0	+0.80
M-39	R	1½	69.2	67.8	−1.4	
M-31	L	2	67.6	68.8	+1.2	
M-32	L	2	69.8	68.9	−0.9	+0.15
M-22	L	4	66.5	67.8	+1.3	
M-26	L	4	69.4	68.7	−0.7	−0.38
M-27	L	4	70.6	69.8	−0.8	
M-10	L	4	65.9	64.6	−1.3	
M-8	L	6	68.4	67.8	−0.6	
M-28	L	6	68.6	68.8	+0.2	−0.38
M-29	L	6	67.4	67.8	+0.4	
M-30	L	6	69.7	68.2	−1.5	
M-17	L	8	66.1	67.7	+1.6	+1.60
M-6	L	10	68.8	67.1	−1.7	
M-15	L	10	68.2	68.6	+0.4	−0.65
M-3	L	12	69.1	70.3	+1.2	+1.00
M-4	L	12	68.5	69.3	+0.8	

* By the t test, the difference between control and experimental groups is not significant over the period between one and twelve weeks.

tribution are in some ways interrelated and that both are important in the determination of physical characteristics of connective tissue [2,8,12,14]. However, the present state of knowledge of the higher organization of extracellular carbohydrate, protein, and water in ground substance is fragmentary. More specific details of their arrangement and interrelationships must be known before the precise relationship between the present data and the changes in the physical characteristics of connective tissue under the circumstances of this study can be stated.

In the experimental situation described, the pattern of change of hexosamine and water in synovial membrane and capsule and in tendon was dissimilar during the short time intervals. They became similar after the longer intervals. The reason for the differences in reaction of the tissues in the early period of immobilization is not clear. Two possibilities which occur are a difference in the rate of metabolism of the two tissues, which might be related to the known differences in blood supply, or simply a different turnover rate for the polysaccharides involved. Figures relating to turnover rates of dog connective tissue are presently not available.

One naturally speculates about the mechanisms by which these events occur. An increase in water concentration has been said to follow depolymerization of

TABLE IV

WATER CONTENT OF SKIN

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Water Content		Difference*	Average
			Control (*Per cent*)	Experimental (*Per cent*)		
M-31	L	2	73.2	68.1	−5.1	
M-32	L	2	71.4	70.2	−1.2	−2.53
M-33	L	2	74.9	73.6	−1.3	
M-22	L	4	76.0	72.1	−3.9	
M-26	L	4	74.4	72.5	−1.9	−1.83
M-27	L	4	73.2	73.5	+0.3	
M-8	L	6	68.8	71.6	+2.8	
M-28	L	6	76.0	73.2	−2.8	−0.30
M-29	L	6	73.1	76.8	+3.7	
M-30	L	6	75.4	70.5	−4.9	
M-17	L	8	72.4	72.3	−0.1	−0.10
M-6	L	10	77.5	75.2	−2.3	−4.80
M-15	L	10	75.0	67.7	−7.3	
M-3	L	12	74.9	74.1	−0.8	
M-4	L	12	75.9	75.8	−0.1	−0.77
M-11	L	12	71.8	70.4	−1.4	

* Over the interval two to twelve weeks the difference between the control and experimental groups is significant by the t test with $P < 0.01$.

TABLE V

WATER CONTENT OF FASCIA LATA

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Water Content		Difference*	Average
			Control (*Per cent*)	Experimental (*Per cent*)		
M-31	L	2	78.8	69.7	−9.1	
M-32	L	2	71.2	63.4	−7.8	−7.43
M-33	L	2	75.6	70.2	−5.4	
M-22	L	4	69.8	70.6	+0.8	
M-26	L	4	74.5	70.1	−4.4	−1.67
M-27	L	4	73.7	72.3	−1.4	
M-28	L	6	77.6	75.2	−2.4	
M-29	L	6	68.4	70.8	+2.4	−0.27
M-30	L	6	73.1	72.3	−0.8	
M-17	L	8	70.0	66.7	−3.3	−3.30
M-15	L	10	68.6	66.3	−2.3	−2.30
M-4	L	12	72.8	65.8	−7.0	
M-11	L	12	70.8	66.9	−3.9	−5.45

* Over the interval two to twelve weeks the difference between control and experimental groups is significant by the t test with $P < 0.01$.

the polysaccharide [8,15]. The measurement of polymerization or depolymerization of the acid mucopolysaccharides has so far depended on indirect methods which are generally unsatisfactory. Depolymerization of the polysaccharide in this tissue may occur, but this is no more than speculation. The concept that ground sub-

TABLE VI

HEXOSAMINE CONTENT OF SYNOVIAL MEMBRANE AND CAPSULE

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Hexosamine Content * Control (*Per cent*)	Hexosamine Content * Experimental (*Per cent*)	Per cent Change †	Average
M-34	L	1	1.76	1.93	+ 9.66	
M-35	R	1	1.56	1.88	+20.51	
M-40	L	1	2.12	1.99	− 6.13	+ 0.03
M-41	R	1	1.96	1.48	−24.49	
M-42	L	1	3.64	3.22	−11.54	
M-43	R	1	2.55	2.86	+12.16	
M-37	R	1½	2.17	1.63	−24.88	
M-38	L	1½	2.90	3.02	+ 4.14	− 4.65
M-39	R	1½	2.65	2.83	+ 6.79	
M-31	L	2	5.03	5.46	+ 8.55	
M-32	L	2	5.63	4.40	−21.85	−13.61
M-33	L	2	4.25	3.08	−27.53	
M-22	L	4	4.65	3.92	−15.70	
M-26	L	4	4.29	4.64	+ 8.16	− 0.79
M-27	L	4	5.70	5.41	− 5.09	
M-10	L	4	4.53	4.96	+ 9.49	
M-8	L	6	4.71	4.14	−12.10	
M-28	L	6	6.81	5.85	−14.10	−12.33
M-29	L	6	4.61	4.59	− 0.43	
M-30	L	6	4.89	3.78	−22.70	
M-17	L	8	7.91	7.58	− 4.17	− 4.17
M-6	L	10	6.30	5.67	−10.00	−10.67
M-15	L	10	3.44	3.05	−11.34	
M-3	L	12	4.57	4.95	+ 8.32	
M-4	L	12	4.10	2.59	−36.83	− 8.32
M-11	L	12	4.23	4.38	+ 3.55	

* Hexosamine values are expressed as milligram per gram dry fat-free tissue.

† Per cent change = E C/C. Over the interval studied the difference between control and experimental groups is significant by the t test with $P < 0.01$.

stance is a two-phase system further complicates the question [14]. Both the colloid-rich phase and the water-rich phase would seem to have been affected under this formulation.

Another point brought out by these results is that connective tissue is not uniformly affected by joint immobility. The specialized connective-tissue structures—hyaline cartilage and meniscus—do not become dehydrated under these circumstances. The fibrocartilaginous meniscus is not affected in either direction. Articular cartilage and muscle have been shown previously to become more hydrated [1,10] after disuse. It has been demonstrated that the increased hydration of muscle of an immobilized leg is an extracellular phenomenon probably related in part to changes in the connective tissue which envelops the muscle fibers [10]. It is difficult to conceive of a single factor which would explain these contradictory alterations in water content. Because of the many factors which are involved in water distribution, it would not be surprising if more than one factor were disturbed by joint immobilization. The dense connective-tissue structures investigated (fascia, skin, and tendon) and the synovial membrane and capsule reacted in the same general way as far as water concentration is concerned if the periods

TABLE VII

HEXOSAMINE CONTENT OF TENDON

Animal	Immobilized Extremity	Period of Immobilization (*Weeks*)	Hexosamine Content * Control (*Per cent*)	Hexosamine Content * Experimental (*Per cent*)	Per cent Change †	Average
M-34	L	1	1.84	2.17	+17.93	
M-35	R	1	1.40	2.05	+46.43	
M-40	L	1	2.71	4.65	+71.59	+27.80
M-41	R	1	2.66	3.29	+23.68	
M-42	L	1	3.97	4.30	+ 8.31	
M-43	R	1	4.35	4.30	− 1.15	
M-37	R	1½	2.30	3.21	+39.57	
M-38	L	1½	4.29	3.55	−17.25	+15.97
M-39	R	1½	2.93	3.68	+25.60	
M-31	L	2	8.25	9.85	+19.39	
M-32	L	2	4.68	5.69	+21.58	+11.24
M-33	L	2	4.13	3.83	− 7.26	
M-22	L	4	4.50	4.22	− 6.22	
M-26	L	4	5.56	4.41	−20.68	−11.26
M-27	L	4	8.31	7.89	− 5.05	
M-10	L	4	6.19	5.38	−13.09	
M-8	L	6	5.81	4.68	−19.45	
M-28	L	6	7.22	6.79	− 5.96	− 6.87
M-29	L	6	6.20	6.14	− 0.97	
M-30	L	6	8.09	8.09	− 1.11	
M-17	L	8	7.98	7.56	− 5.26	− 5.26
M-6	L	10	4.85	4.99	+ 2.89	− 2.38
M-15	L	10	3.53	3.26	− 7.65	
M-3	L	12	5.90	4.82	−18.31	
M-4	L	12	5.24	4.49	−14.31	−16.79
M-11	L	12	5.24	4.31	−17.75	

* Hexosamine values are expressed as milligram per gram dry fat-free tissue.

† Per cent change = E-C/C. Over the period four to twelve weeks, the difference between control and experimental groups is significant by the t test with $P < 0.01$.

of study beyond four weeks are considered. Chondroitin sulphate B is thought by Meyer to be the major acid mucopolysaccharide associated with the coarse type of collagen bundles. The dense connective-tissue structures just listed all contain coarse collagen bundles and may have a fairly uniform acid mucopolysaccharide pattern. If so, this fact may help to explain the uniform change in those structures.

A careful study of the enzyme systems, which are important in the buildup and breakdown of mucopolysaccharide molecules, and a study of over-all energy relationships will be necessary to elucidate the mechanisms involved in the events described in this study. Studies on turnover rates of hyaluronic acid and chondroitin sulphate in control and experimental extremities are indicated, in addition to the more complete characterization of the polysaccharides present.

The loss of water and polysaccharide described here parallels the changes described in aging skin [30]. Since the physical changes of aging connective tissue toward a more rigid state also parallel the events under study one naturally questions whether an accelerated age-related process is taking place.

Verzar has expressed the opinion that cortisone and ionizing radiation influ-

TABLE VIII

HYDROXYPROLINE DETERMINATIONS*

Animal	Control	Experimental	Difference †
M-31	96.8	94.7	−2.1
M-13	84.9	87.6	+2.7
M-8	86.3	92.5	+6.2
M-19	97.8	103.3	+5.5
M-23	96.3	88.3	−8.0
M-15	103.1	101.5	−1.6
Average			+0.45

* Results are expressed in milligram hydroxyproline per gram dry fat-free tendon.
† Using the t test, there was no significant difference between control and experimental groups. ($P > 0.05$.)

TABLE IX

GLUCOSAMINE AND GALACTOSAMINE CONCENTRATION IN NORMAL DOG TENDON

	Milligram per Gram Dry Fat-Free Tendon
Total hexosamine	1.448
Galactosamine	1.260
Glucosamine	0.185
	Ratio Glucosamine/Galactosamine 0.147

ence ground substance rather than the collagen fiber itself and is of the opinion that if mucopolysaccharide is destroyed, the fiber will age.

Verzar and others [2,18,19,34] have postulated that the differences which have been noted between collagenous tissue of the old and young animal can be best explained by thermal denaturation at body temperature or a physiological tanning process mediated by formaldehyde or other naturally occurring aldehydes. In either case, it is thought that new cross linkages between collagen fibers would be created. These inferences are drawn from a wide range of observations on differences between collagenous tissue of old and young animals. The age-related changes noted in the connective tissue of older animals include: decreased solubility in dilute acetic acid [18,34], decreased base-binding capacity [18], decrease in Young's modulus and breaking stress of collagen fiber [18], decreased swelling in acid and alkali [6,17], decrease in the velocity constant of relaxation [9], decreased susceptibility to collagenase [19], increased rigidity of collagen [18], increased bulk modulus [18], increase in the weight necessary to inhibit thermic contraction [34], and increase in calcium-binding capacity [13,34].

Studies in these parameters are in progress by the author to determine whether further parallels exist between the changes in connective tissue due to immobility and those due to aging.

With the experimental observations in mind, possible explanations of joint stiffness may be considered. Scar formation in the joint capsule was eliminated by definition as a type of joint stiffness being considered here. Changes in elastic-fiber content sufficient to influence joint mobility are not likely to have occurred because of the relatively inert nature of elastic fibers metabolically [28]. Shortening of collagen fibers and accommodation to a fixed joint position where less tension is applied to the ligaments is not a likely explanation of joint stiffness if the present concepts of the molecular configuration of the collagen molecule are valid [25]. Such a molecule could not shorten without severe disorganization and disruption of its

normal configuration. New collagen fibers which are produced would be laid down according to the resting length of the ligaments and might be placed under tension as the joint is remobilized. The slow rate of turnover of collagen [32] necessarily reduces the significance of this factor, although it undoubtedly occurs to a certain extent. The factor of proliferation of connective tissue of the perimysium and endomysium is alluded to in numerous papers which deal with the histopathology of immobilized or denervated muscle [11,31,33]. Such newly formed connective tissue would create a mechanical obstruction to full contraction and relaxation of an affected muscle and would be expected to restrict joint mobility. However, the possibility that the normally slow turnover rate of collagen receives a stimulus in the immobilized joint is refuted by the work of Brooke and Slack who demonstrated reduction of synthesis of collagen in both skeletal and soft tissues of the atrophying rat limb. In particular, decreased synthesis of the neutral-salt-soluble precursor of collagen was demonstrated in the experimental leg.

The rapid turnover rates of the mucopolysaccharides [27] mean that the interference in the buildup or breakdown of these molecules will be quickly felt. Two phenomena could be responsible for joint stiffness in this regard: first, a change of the lubricating mechanism; and second, changes in the cross-bonding of adjacent collagen bundles. Loss of mucopolysaccharide could remove the buffer between collagen bundles and facilitate cross linkages between those fibers which become juxtaposed in the immobilized limb. Such changes could presumably make the tissue containing the collagen more rigid and less plastic and yielding; these changes might contribute to the joint stiffness seen clinically.

The relative importance of new-collagen production versus alteration in the mucopolysaccharide content as causal factors in the production of contractures presumably changes with time. Because of the slow rate of collagen turnover, the importance of new collagen fibers as the cause of joint rigidity should be negligible after only a few weeks of immobilization. It is suggested that the more rapid alterations in polysaccharide, water, and electrolyte may be the key to the joint stiffness seen in these early intervals. As time passes, new-collagen production, however small, may gain in importance and presumably be more difficult to reverse.

SUMMARY

1. A time study is presented in which alterations in the concentration of water and hexosamine were observed in connective-tissue structures about immobilized knee joints of dogs.

2. The reaction to immobility was not uniform in the different connective tissues studied. Differences in rate and direction of change are described.

3. After four to twelve weeks of immobilization, the water concentration was reduced in tendon, synovial membrane and capsule, skin, and fascia by 2 to 3 per cent.

4. Hexosamine was reduced about 10 per cent in synovial membrane and capsule and in tendon over the four-to-twelve week period.

5. Correlation between experimental findings and present concepts of connective-tissue metabolism has led to a hypothesis concerning the mechanism of development of joint contractures.

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Giant-Cell Tumors of Bone in South India

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As most reported series of giant-cell tumors with which we are familiar are those from Great Britain or the United States, we concluded that it would be informative to review the giant-cell tumors treated at the Christian Medical College of Vellore, South India. During the ten years from 1950 through 1959, 118,519 patients were admitted to the hospital and a vastly larger number were seen in the out-patient clinic. The hospital of the College is a teaching hospital of over 700 beds, located in Madras State in the Tamil-speaking area and close to the border of Andhra Pradesh where Telugu is spoken. The peoples of both these language groups are of Dravidian extraction and are considered to be descendants of the original inhabitants of India. Although patients come to this hospital from all over India, the majority come from within a radius of a few hundred miles and are thus mostly Dravidian in origin. They come from various economic strata, ranging from the wealthy to the very poor, the latter far outnumbering the former. Because as a rule only patients with more serious conditions seek help at this institution, there is an element of selection present, and the incidence of tumors encountered here has little significance as an indication of the relative frequency of tumors in the general population of this region. Despite this, it is of some interest that when Hadley and associates, from the Pathology Department of this hospital, reviewed the bone tumors for the twelve years from 1943 to 1955, they found that twenty-four giant-cell tumors were listed, as compared with sixteen osteosarcomata, five fibrosarcomata, and six Ewing tumors.

During the ten years covered by the present study, thirty-three giant-cell tumors were seen. In all of these, the microscopic picture was considered typical. Such conditions as aneurysmal bone cyst, of which three were diagnosed in the same interval, were excluded. The tissues from these patients had all been examined originally by senior members of the pathology department, and most of them were graded by the method of Jaffe, Lichtenstein, and Portis. The present study included an independent review of the slides and a comparison of our grading with that previously done. In only a few cases was there a difference of opinion as to the grade between the original report and this study.

The present series included eighteen male and fifteen female patients; their average age was 28.3 years. The youngest patient was a twelve-year-old boy with a Grade I giant-cell tumor of the maxilla, and the oldest was a fifty-six-year-old woman with a Grade II tumor of the distal portion of the radius. Table I lists these patients by sex and age and by the location and grade of the tumor.

There were eight tumors in the distal portion of the radius, seven in the proximal portion of the tibia, five in the distal portion of the femur, three in the metacarpals, two in the proximal portion of the humerus, and one each in eight other bones, including a rib. The tumor which originated in a rib later spread to an adjacent vertebra and caused pressure on the spinal cord.

The age at admission of the patients in this series ranged from twelve to fifty-six years. Seven were under twenty-one; twenty were from twenty-one to thirty-

five years old; five were thirty-six to forty-five years old; and one was over forty-five. In many instances the presence of the tumor had been noticed several months before admission. As a general rule, the patients did not seek medical care until their tumors had become relatively large. Since many of the patients were illiterate it is quite possible that some did not know their age accurately. We were aware that the finding of seven of thirty-three patients with giant-cell tumors under the age of twenty-one was at variance with the age distribution usually reported. Accordingly, we were especially critical in reviewing these cases before they were classified as giant-cell tumors.

FIG. 1

Giant-cell tumor, Grade I. The stroma shows little pleomorphism and giant cells are numerous (× 100).

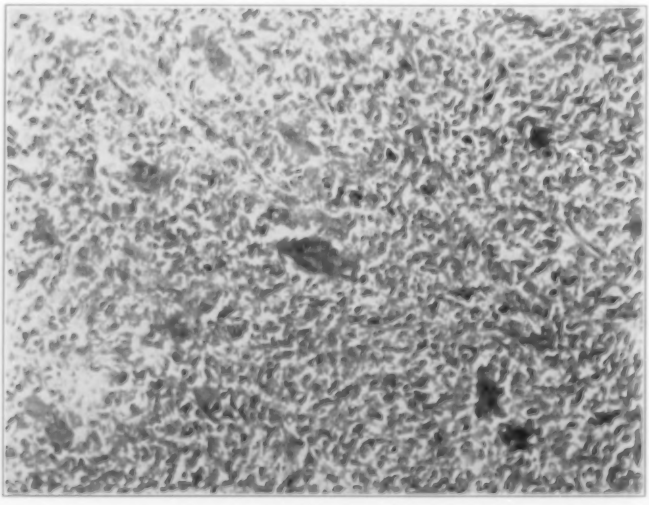

FIG. 2

Giant-cell tumor, Grade II. The stromal cells are quite plump and numerous and giant cells are fewer than in Grade I (× 100).

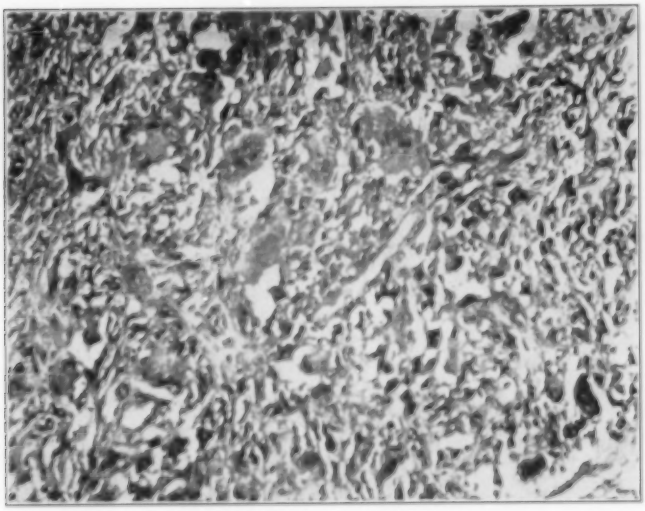

FIG. 3

Giant-cell tumor, Grade III. The stromal cells are pleomorphic and giant cells are few (× 100).

HISTOLOGICAL CHARACTERISTICS

The tumors were graded according to the classification of Jaffe and associates. Figures 1, 2, and 3 show representative histological sections of the three grades of tumor in this series. Grades I and II accounted for all but three of the thirty-three tumors (91 per cent). Two of the three patients with Grade III tumors were under twenty-one years of age. Seven of the eight tumors in the distal portion of the radius were Grade II. Gupta and Andleigh of Jaipur, in northern India, recently reported twenty-four patients with giant-cell tumor, eight of whom were under twenty years of age. In their series 46 per cent of the tumors were Grades I and II.

ROENTGENOGRAPHIC CHARACTERISTICS

Roentgenograms could be located for only nineteen of the thirty-three patients. In many cases these revealed evidence of large tumors; however, the soap-bubble appearance which has frequently been thought to be characteristic of these tumors was seen in only two or three roentgenograms—most simply showed at the end of a long bone, areas of bone destruction without new-bone formation. There was no correlation between the roentgenographic appearance and the histological grading of these tumors. Figures 4, 5, and 6 are representative roentgenograms.

TREATMENT

Ten of the patients in this series received radiation treatment. A sixteen-year-old girl with a Grade III tumor of the distal portion of the femur was treated in 1953 by implantation of thirty milligrams of radium for seven days. An eighteen-year-old boy with a Grade II tumor of the distal portion of the tibia was given deep x-ray therapy (4,224 r). Both of these patients disappeared and there was no follow-up information as to the results of therapy. Of the remaining eight patients who received x-ray therapy in doses ranging from 1,800 to 5,200 r all subsequently returned for surgical treatment because of failure of the radiation to effect a cure. Thus, in no patient in whom the result is known did radiation effect a cure.

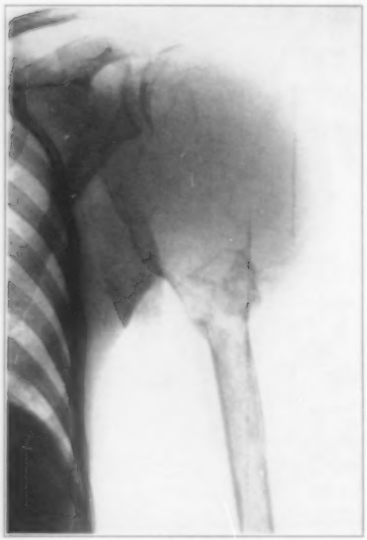

FIG. 4

FIG. 5

Fig. 4: The roentgenogram shows multilocular giant-cell tumor (Grade I) in the upper end of the left humerus (specimen shown in Fig. 1).

Fig. 5: Huge multiloculated giant-cell tumor (Grade I) in the upper end of the tibia.

FIG. 6

Giant-cell tumor (Grade II) in the distal end of the radius.

Thirty-one patients were treated surgically: four had thigh amputations, seven were treated by curettage and bone chips, and nineteen were treated by excision and bone-grafting. The patient with the primary tumor in a rib, which later spread to a vertebral body, was treated first by radiation; later, a surgical procedure was done to decompress the spinal cord. The long-term results of these surgical procedures are not known. A satisfactory follow-up study is made difficult by several factors. Poverty frequently prevents patients from returning to the hospital for observation, and language barriers and illiteracy interfere with attempts

TABLE I

GIANT-CELL TUMORS

Sex, Age, and Site of Various Grades

	Hospital Number	Sex	Age (*Years*)	Site
		GRADE I		
1.	30156	Female	26	Tibia, upper
2.	49088	Female	40	Humerus, upper
3.	38024	Female	35	Femur, lower
4.	54038	Female	30	Metacarpal, fifth
5.	63996	Male	23	Tibia, upper
6.	77586	Female	25	Metatarsal
7.	3968	Male	21	Tibia, upper
8.	6771	Female	34	Femur, upper
9.	15244	Female	15	Metacarpal, third
10.	6461	Male	12	Maxilla
11.	41720	Male	40	Radius, lower
12.	45917	Male	35	Tibia, upper
13.	31531	Female	25	Ulna, lower
		8 Female 5 Male	Average, 27.8	
		GRADE II		
1.	36310	Male	35	Radius, lower
2.	34462	Male	33	Radius, lower
3.	34948	Male	28	Tibia, upper
4.	43929	Male	33	Radius, lower
5.	72965	Male	18	Tibia, lower
6.	66271	Female	24	Femur, lower
7.	55907	Female	18	Metacarpal, first
8.	51263	Male	28	Radius, lower
9.	78235	Male	20	Tibia, upper
10.	103006	Male	40	Femur, lower
11.	106730	Male	42	Radius, lower
12.	126057	Female	56	Radius, lower
13.	128496	Female	22	Tibia, upper
14.	1643	Male	35	Mandible
15.	17881	Male	30	Femur, lower
16.	41910	Female	35	Humerus, upper
17.	27524	Female	40	Radius, lower
		6 Female 11 Male	Average, 31.6	
		GRADE III		
1.	106814	Male	13	Fibula, upper
2.	104239	Male	26	Rib
3.	133	Female	16	Femur, lower
		2 Male 1 Female	Average, 18.3	

to get information by mail. Since eight of the ten patients receiving radiation returned for further treatment when the tumor recurred, it might be assumed that some of the patients treated by surgery would also have returned if their results were unsatisfactory.

SUMMARY AND CONCLUSIONS

Thirty-three patients with giant-cell tumors of bone were treated in Christian Medical College Hospital at Vellore, South India, during the ten years from 1950 through 1959. There were eighteen male and fifteen female patients whose ages ranged from twelve to fifty-six years. Twenty patients (61 per cent) were twenty-one to thirty-five years old. Seven (21 per cent) were under twenty-one years of age. Thirteen (39 per cent) of the tumors were classed as Grade I, seventeen (51 per cent) as Grade II, and three (9 per cent) as Grade III. The three Grade III tumors occurred in young patients, thirteen, sixteen, and twenty-six years old. This distribution of histological grades agrees quite closely with that reported by Gupta and Andleigh from a series of twenty-four cases studied in Jaipur, in northern India. Giant-cell tumors were the most frequently encountered primary bone tumor in this general teaching hospital which draws the majority of its patients from the Dravidian peoples of southern India. Since seven of the thirty-three patients in this series were less than twenty-one years old, this study would suggest that giant-cell tumors are more frequently found in the younger-age group in southern India than in some other countries.

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A Method for Reinsertion of the Distal Biceps Brachii Tendon

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Over the past twenty years, a number of articles have appeared on rupture of the distal biceps brachii tendon and its treatment. Approximately 100 cases have been reported of this uncommon condition.

The primary discussion in these articles is whether the tendon should be reattached at its normal point of insertion on the radial tuberosity or whether it should be attached to some more convenient location on the anterior aspect of the elbow, usually to the tendon of the brachialis. Suturing the biceps tendon to the tendon of the brachialis simplifies the operation, but it ignores the fact that the biceps is the most powerful supinator of the forearm. Steindler observed that with the elbow extended, the supinator is capable of performing about half the work of the biceps in carrying out supination; with the elbow flexed, the power supplied by the biceps is even greater.

In reported cases of reinsertion of a ruptured distal biceps tendon into the radial tuberosity, the operation was performed through an anterior approach. But those authors who favor suture of this tendon to the brachialis, notably Dobbie and Meherin and Kilgore, comment on the difficulties and dangers of reinserting it in the radial tuberosity by means of the anterior approach. Meherin and Kilgore reported that in a group of six patients in whom the biceps tendon was reinserted into the radial tuberosity, two had permanent partial damage to the radial nerve. A lesion of the radial nerve occurred in a third patient, but the exact location of reinsertion of the tendon was unknown. Dobbie's series included two such complications. Referring to the anterior approach, Dobbie stated: "the operator was impressed with the numerous important structures identified and confined in this anatomical region and was thoroughly convinced that exposure of the tubercle by this exposure was both impractical and unwise".

The purpose of this paper is to recommend a different method of insertion of the distal biceps tendon into the radial tuberosity which we believe has definite advantages. Not only is the tendon replaced in its anatomical insertion, with restoration of supinatory power, but the replacement is accomplished with relative ease and without the difficulties and dangers inherent in the anterior approach. This method has been used in three patients by members of the Campbell Clinic staff with good results and without nerve damage or vascular complications.

TECHNIQUE

With the patient in the supine position, under general anesthesia, with tourniquet control and with the elbow in extension, a curvilinear incision is made over the anterior aspect of the elbow, as shown in Figure 1. The deep fascia is incised and the tendon of the biceps located; it is usually found retracted two or three inches above the elbow. Care should be taken to protect the lateral antebrachial cutaneous nerve. A heavy silk suture is placed in the tendon with both ends emerging through the distal tip (Fig. 1). The opening of the canal through

which the tendon originally passed between the radius and the ulna is located with a blunt instrument.

The forearm is then flexed, and a second incision is made over the postero-lateral aspect of the elbow. This is the incision previously described [1] for exposure of the proximal portion of the ulna and the upper end of the radius, which we have used for Monteggia fractures [4] and for fractures of the olecranon with associated fractures of the head of the radius. The muscles attached to the lateral surface of the olecranon are detached and retracted laterally along the plane of the interosseous membrane, exposing the head and neck of the radius. The deep

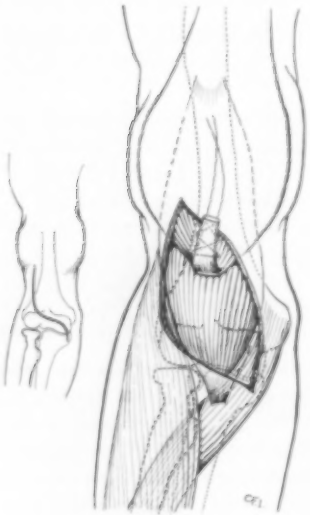

FIG. 1

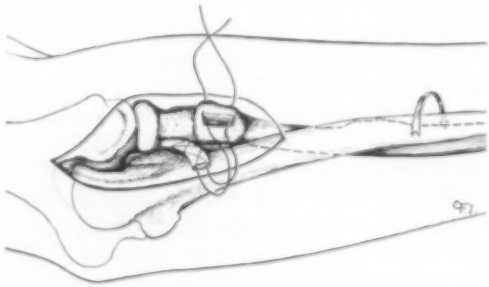

FIG. 2

Fig. 1: On the left is shown the line of the anterior skin incision. In the larger drawing, the retracted biceps tendon is seen in the upper portion of the incision with a silk suture in place. By retracting the distal end of the incision, the canal of the biceps tendon is located between the brachialis and the pronator teres on the medial side and the brachio-radialis on the lateral side.

Fig. 2: The radial tuberosity as seen through the posterior approach. Note the full pronation of the radius. The suture is in place, preparatory to insertion of the end of the tendon into the trap door.

branch of the radial nerve is not seen; it enters the forearm by winding around the neck of the radius between the planes of the supinator and is protected by the substance of this muscle when the supinator is retracted laterally. By fully pronating the forearm, the radial tuberosity is exposed, as shown in Figure 2. A trap door is made in the radial tuberosity and two drill holes placed opposite the hinge.

Attention is again directed to the anterior incision, and the ends of the silk suture previously placed in the biceps tendon are passed through the canal of the tendon by means of a tendon carrier or a hemostat. Traction on the suture pulls the tendon through the canal and into the posterior exposure. The suture ends are threaded through the trap door and out the drill holes. Tension on the tendon is released by flexing the elbow. The end of the tendon is placed in the trap door; and, while held in this position with forceps, the silk suture is securely tied. After placing reinforcing sutures from the tendon to the adjacent soft tissue, the incisions are closed and a posterior plaster splint applied with the elbow flexed 10 degrees above a right angle and the forearm in moderate supination.

The cast is removed in five to six weeks, and gradually increasing active exercises are instituted.

SUMMARY

A method of repair following rupture of the distal tendon of the biceps brachii is described. This method has two advantages. First, it restores the tendon to its

anatomical insertion and the biceps to its function as a supinator as well as a flexor of the forearm. Second, the use of two approaches obviates the difficulties and dangers of exposing the radial tuberosity through the anterior approach.

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Undermining Burrowing Ulcer Complicating Post-traumatic Prepatellar Bursitis

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The following case report is that of an apparently simple infection, which, when treated in a routine manner, followed anything but a routine course, ending with prolonged hospitalization, multiple surgical procedures, and rather marked permanent scarring. The case illustrates the occasional occurrence of unusual infections which are quite resistant to ordinary therapeutic measures but which will respond to specific therapy.

G.M., a Negro female patient, forty-nine years old, known to our Diabetic and Hypertension Clinic, had fallen ten days prior to her admission to the hospital on February 13, 1959, sustaining an abrasion over the right patella approximately two centimeters in length. She had remained in bed since the injury because of pain and swelling of the right knee.

Upon admission, her temperature (oral) was 100 degrees Fahrenheit. Overlying the right patella was an abrasion within which there was a small fistulous opening draining pus. The prepatellar tissues were swollen, and there was some effusion in the knee joint. Increased local warmth and slight restriction of motion of the right knee, as compared with the left, were also noted.

Analysis disclosed acetonuria and a brick red color on testing for urine sugar. Her blood sugar was 287 milligrams per 100 milliliters.

Treatment of her diabetes was initiated immediately and incision and drainage of the right

prepatellar region was performed immediately after admission. Twenty cubic centimeters of pus was evacuated from the prepatellar bursa, which was then irrigated with a liter of normal saline solution. The wound dressing incorporated two polyethylene catheters extending into the wound for purposes of irrigation. A toe-to-groin plaster cast was applied for immobilization, with a window at the operative site. Culture of material taken at the time of surgery was reported as growing nonhemolytic streptococcus, alpha and beta hemolytic streptococcus, and *Staphylococcus albus*, all of which were sensitive to the common antibiotics. Chloromycetin was administered postoperatively, and the catheters leading into the wound were irrigated every three hours with a solution of 0.5 per cent neomycin. The patient's subsequent course is summarized in Chart I.

Three days after operation the chloromycetin was discontinued because the infection showed no improvement. Penicillin, 600,000 units, was then given intramuscularly twice a day; but six days later it was discontinued because the infection continued to progress. Tetracycline was used next in the usual dosage until February 28, 1959, the fifteenth postoperative day. During this period the patient continued to be febrile, and, on two occasions, additional small pockets of pus in the upper portion of the wound had been opened to afford better drainage. On March 5, 1959, the patient was taken to the operating room and all demonstrable extensions of the infection were unroofed, under general anesthesia, so that no pocketing remained. Despite these measures the

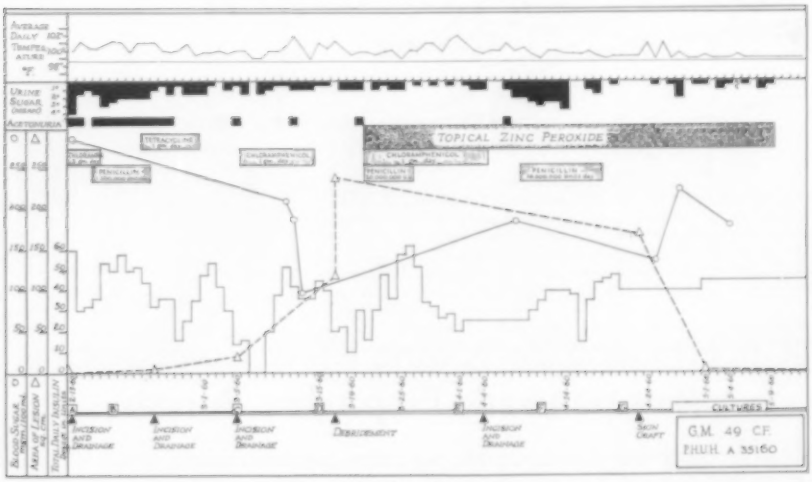

CHART I

infection continued to spread up the thigh along the plane of the quadriceps fascia, and the patient remained febrile. On March 17, 1959, another wide incision with débridement was performed. The resulting open wound measured approximately thirty centimeters in length and eight centimeters in width and penetrated down to the muscle fascia. After this procedure the patient was given 20 million units of penicillin intravenously and two grams of chloromycetin orally daily. It was not until this time that the true nature of this patient's condition was recognized. The bacteriologist was asked to look for microaerophilic streptococci in the culture; these were reported as being abundant. Zinc peroxide dressings, utilizing the technique of Meleney, were used thereafter, starting on March 20, 1959. No further extension in the area of the infection or ulceration occurred, although one small pocket of infection in the upper portion of the incision did require further incision (Fig. 1). On April 23, 1959, pinch grafts, obtained from the opposite thigh, were applied in order to hasten the epithelialization of the wound. Pinch grafts were used in preference to a split-thickness graft because of the profuse secretion from the wound. By May 17, 1959, the entire area was epithelialized. Active motion was started on May 21, 1959, and, by the time of her discharge from the hospital on June 4, 1959, the range of motion in the right knee was from 175 to 85 degrees. Two weeks later, when she was seen in the out-patient department, there was a normal range of motion of the right knee as compared with that in the left. This range of motion has been retained.

DISCUSSION

It must never be forgotten that in the management of any infection, basic

TABLE I

CULTURES

2–13–59	*Staphylococcus albus* [a]; Streptococcus (non-hemolytic, alpha and beta hemolytic), Bacteroid (moderate), *Neisseria catarrhalis*
2–18–59	*Staphylococcus albus;* non-hemolytic streptococcus [a] (charted simply as "non-hemolytic streptococcus" but subsequent check of original laboratory records revealed that the organism was a strict anaerobe—a fact that had not been conveyed to the patient's chart)
3– 5–59	Streptococci, non-hemolytic [a]
3–15–59	Streptococci, non-hemolytic and alpha-hemolytic, both aerobic and anaerobic [a]
4– 1–59	Anaerobic streptococci [a] (occasional)
4–11–59	Enterococci [b] (abundant)
4–21–59	Enterococci [b] (moderate)

a Sensitive to penicillin, streptomycin, tetracycline, chloromycetin, novobiocin, furadantin, and erythromycin.

b Sensitive to penicillin and chloromycetin.

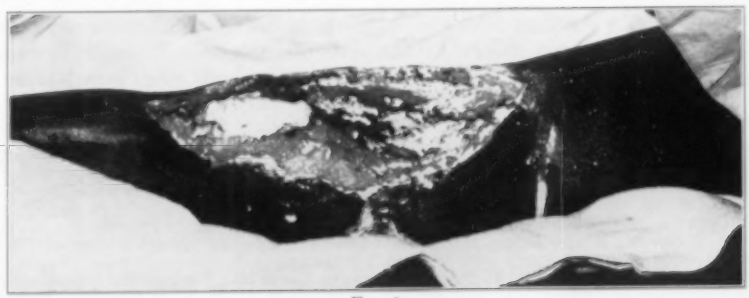

FIG. 1

Appearance of the ulcerated area March 25, 1959, five days after initiation of zinc peroxide treatment.

FIG. 2

Appearance January 27, 1960.

surgical principles must be adhered to. This requires adequate drainage of the infection and the elimination of necrotic debris. At times, however, this alone, or even in combination with antibiotics, is not sufficient to control the infection. In such a situation the use of zinc peroxide locally in the wound should be considered. Meleney has recommended its use in undermining burrowing ulcers, progressive

bacterial synergistic gangrene, mixed infections with hemolytic *Staphylococcus aureus* and hemolytic streptococcus, and foul-smelling infections (such as gas gangrene), Vincent's angina, and necrosis after roentgen therapy. In the present case, the use of zinc peroxide locally certainly appeared to be of significant benefit. Unfortunately, we cannot state unequivocally that it alone was responsible for the dramatic improvement the patient exhibited, since massive doses of antibiotics were started at the same time as the Meleney treatment.

CONCLUSION

The case reported is thought to be of interest and value because it illustrates the following features, which may be forgotten or overlooked.

1. Bacterial infection may not be controlled by antibiotic therapy even when *in vitro* tests indicate that the organism is sensitive to the specific antibiotic being used.

2. Antibiotic therapy is not a substitute for, but is an adjunct to, adequate surgical care and good surgical judgment.

3. In certain resistant infections, the solution of the problem presented may lie in the use of measures specific for the particular situation. Unless such unusual situations are promptly recognized, effective therapy may be unduly delayed.

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Post-Fracture Vascular Phenomena and Long-Bone Overgrowth in the Immature Skeleton of the Rat*†

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Several investigators have observed that a fractured extremity in a growing child may grow longer than its opposite unfractured member [1,2,4,5,7,13]. Most have concluded that hyperemia of the fractured bone leads to epiphyseal stimulation with resultant overgrowth of that bone. The hyperemic process is considered to be local in extent, with its effect limited to the fractured bone. Compere and Adams stated, and other writers implied, that overgrowth resulting from gross mechanical trauma to one long bone does not occur in bones of other segments of the extremity.

Contrary to the conclusions reached by earlier writers [11], recent work has shown that the hyperemia which follows fracture is not confined to the fractured bone, but involves the entire extremity [15,16,17]. If the entire limb takes part in the hyperemic process and if the hyperemia is related to the phenomenon of overgrowth, it is difficult to see why epiphyseal stimulation would not occur throughout the traumatized extremity.

In the experimental evaluation of a possible relationship between long-bone overgrowth and vascular changes after fracture, one must keep in mind that the vascular changes may vary according to the time after fracture. Studies now completed show that a marked increase in arterial flow into an extremity occurs within minutes of the time of fracture of one of the long bones in the limb [19]. Several days later, the vascular bed of the entire limb undergoes chronic enlargement [18]. In the work being reported no attempt was made to measure arterial flow. Vascular-bed volume changes, on the other hand, were measured with the plastic injection technique.

We estimated growth by direct measurement of the length of the femur in each animal. Experimental and control animals were compared in an effort to determine if growth alterations after fracture varied from the normal expected growth. Previous writers [1,2,4,5,7,13] apparently did not give serious thought to the possibility that unilateral or bilateral growth retardation might contribute to the general impression that overgrowth occurs in the fractured limb. It would not be too surprising to observe retardation of growth in the light of the decrease in arterial blood flow, which has been noted to occur in the non-fractured hind limb of an experimental animal when the opposite tibia was fractured [17].

With these basic problems in mind, this study was designed to test the following questions:

1. Is long-bone overgrowth after fracture confined to the fractured bone or do the other long bones in the extremity take part as well?

2. Does the overgrowth that occurs in a fractured limb represent an absolute increase in length, or does either unilateral or bilateral retardation of growth play a part?

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TABLE I

ALLOCATION OF EXPERIMENTAL ANIMALS IN THIS STUDY *

Days after Fracture	Group A Fracture and Plastic Injection	Group B Fracture and Femur Measurement	Group C Controls: Femur Measurement Only
3	9	9	9
6	9	9	9
9	9	9	9
12	9	9	9
15	9	9	9
18	9	9	9
21	9	9	9
24	9	9	9
27	9	9	9
30	9	9	9
33	9	9	9
36	9	9	9
39	9	9	9
42	9	9	9
45	9	9	9
48	9	9	9
Totals	144	144	144

* The total of 432 weanling rats used in this experiment were randomly separated into two treatment groups and one control group. Group A was injected at three-day intervals following fracture. In Group B the femora on the fractured and non-fractured sides were measured. Femur lengths were also obtained in Group C, or control animals.

3. Is there a correlation between long-bone overgrowth after fracture and the enlargement of the vascular bed that follows fracture?

MATERIALS AND METHODS

Four hundred and thirty-two male rats of the C. F. Nelson strain were used in this study, which extended over a period of forty-eight days. All animals were obtained from the same supplier and were weaned just prior to the start of the experiment. All were four weeks of age when the study was begun. The animals were housed in metal cages in groups of nine and were fed a standard laboratory diet of Purina rat chow. All rats were assigned random numbers, using Fisher and Yates' tables; these numbers determined the sacrifice day and treatment group to which each rat was allocated. Three treatment groups of equal size were established and designated as A, B, and C (Table I).

In Groups A and B, a closed fracture of one tibia was produced manually under ether anesthesia. Right and left tibiae were fractured alternately. No effort was made to immobilize the fracture, and the animals were allowed to run free in their cages. Group C animals were maintained as non-fractured controls. Roentgenograms were made of all experimental animals and those with incomplete or open fractures were discarded from the series.

Beginning on the third day after fracture and on every third day thereafter through the forty-eighth day, nine rats from each group were killed with an overdose of ether. After death the animals were treated in the following manner:

In Group A, the sternum was resected and the thoracic aorta cannulated to permit injection of the lower trunk and hind limbs with methyl methacrylate. After the plastic had hardened, both hind limbs were disarticulated at the hip and were then macerated with solutions of potassium hydroxide and hydrochloric acid to remove all animal and mineral matter. The plastic cast of the vessels of the whole limb that remained after maceration was then weighed with an analytic

TABLE II

MEAN WEIGHTS IN GRAMS OF PLASTIC MOLD ON FRACTURED AND NON-FRACTURED SIDES AND RESULTS OF STATISTICAL TESTS (t) OF PAIRED COMPARISON BASED ON MEAN DIFFERENCES *

Days after Fracture	Mean Weights of Plastic Mold		t Values
	Fractured Side	Non-Fractured Side	
3	.448	.469	− .39
6	.561	.687	−4.42‡
9	.720	.714	1.60
12	.509	.491	.78
15	.270	.242	1.68
18	.606	.621	− .64
21	.860	.841	.56
24	1.528	1.218	1.45
27	1.451	1.252	1.74
30	.821	.782	2.99†
33	1.412	1.460	− .63
36	1.189	1.262	−2.07
39	1.328	1.329	− .02
42	.994	1.014	− .63
45	.892	.848	2.38†
48	1.232	1.250	−1.10

* The mean weights of the plastic molds of fractured and non-fractured limbs of the A group of animals are given here; t values of statistical significance are indicated.
† Probability associated with t value less than .05.
‡ Probability associated with t value less than .01.

balance. The weight of the plastic cast of the vessels of each limb was then compared with the weight of the cast of its opposite member. This technique has been described in detail elsewhere [18].

In Group B, the limbs of the animals were disarticulated at the hip. Both femora were carefully dissected free of soft tissue. Each bone was measured lengthwise with a Vernier caliper from the articular surface of the femoral head to the articular surface of the distal end of the femur. All measurements were carried out three times and to the nearest one-thousandth of an inch. The mean value of the three measurements was calculated and used in the later analysis. Variation between measurements of each bone was inconsequential.

The limbs of Group C, the control animals, were also disarticulated at the hip. The femora were then dissected free to permit measurement and length comparisons. All femur-length measurements in this experiment were done immediately after death to avoid possible loss of length by drying of the tissue.

RESULTS

The data obtained from the vascular volume studies, as measured by the plastic injection technique, are presented in Table II. It is of interest to note that there was a significantly smaller mean plastic-mold weight on the side of the fracture at the sixth day. Thereafter, the plastic-mold weights of the fractured limbs became heavier than the unfractured side until the thirty-third day with one exception, the eighteenth day. On the thirtieth day, the mean weight of the fractured sides was significantly greater than the mean weight of the non-fractured sides. In the light of contrary findings in previous studies which utilized this technique, it is difficult to ascribe biological significance to the heavier mean weights of the non-fractured side on the eighteenth day, on the thirty-third through forty-second day, and on the forty-eighth day. The apparent significance of the difference on the forty-fifth day is no easier to explain than the other

TABLE III

MEAN FEMUR LENGTHS IN INCHES OF EXPERIMENTAL AND CONTROL GROUPS ON VARIOUS DAYS AFTER FRACTURE *

Days after Fracture	Fracture	Non-Fracture	Control
3	.762	.764	.801
6	.894	.888	.883
9	.932	.920	.922
12	1.012	.999	.953
15	1.036	1.024	1.015
18	1.042	1.033	1.041
21	1.086	1.071	1.082
24	1.117	1.111	1.109
27	1.131	1.124	1.127
30	1.182	1.167	1.169
33	1.191	1.179	1.196
36	1.203	1.195	1.211
39	1.220	1.209	1.248
42	1.220	1.218	1.213
45	1.269	1.259	1.241
48	1.263	1.255	1.272

* The mean femur lengths of paired fractured and non-fractured limbs are given in Columns 2 and 3. In Column 4 are listed the mean femur lengths of the control animals.

TABLE IV

t VALUES OF VARIOUS COMPARISONS OF FEMUR LENGTH ACCORDING TO DAYS AFTER FRACTURE *

Days after Fracture	Fracture Minus Non-Fracture[1]	Fracture Minus Control[2]	Non-Fracture Minus Control[2]
3	− .66	−3.16‡	−3.23‡
6	3.08†	.74	.34
9	.28	.56	− .11
12	4.54‡	3.25‡	2.55†
15	4.48‡	1.48	.65
18	.96	.11	− .74
21	7.26‡	.26	−1.10
24	5.06	.58	.15
27	3.38‡	.25	− .18
30	4.91‡	.96	− .17
33	4.28‡	− .56	−1.62
36	.29	− .44	− .88
39	6.76§	−2.18†	−2.96‡
42	.42	.42	.32
45	2.87†	1.82	1.18
48	2.22	− .95	−1.73

* In Column 2 the t values of the mean differences between paired femora from the fractured and non-fractured limbs of experimental animals are listed. In Columns 3 and 4 the differences between the mean lengths of fractured and non-fractured femora and the mean lengths of control femora are considered.

[1] Paired comparisons: femur length of fractured side minus femur length on non-fractured side tested against the hypothesis that the mean difference is zero.

[2] Group comparisons: average femur length of experimental group minus average length of control femora against the hypothesis that the experimental mean minus the control mean equals zero.

† P less than .05.
‡ P less than .01.
§ P less than .001.

differences. A repetition of this experiment by independent investigators may demonstrate the reality or spuriousness of these differences.

The mean femur lengths of the fractured extremities were consistently longer

than the mean femur lengths of the opposite non-fractured extremity from the sixth day through the conclusion of the experiment (Table III). The differences between paired femora from fractured and non-fractured limbs were often quite striking (Fig. 1). When these data are subjected to tests for paired comparisons, it is clear that the majority of differences on the various days cannot readily be attributed to chance; that is, they are statistically significant (Table IV, Column 2).

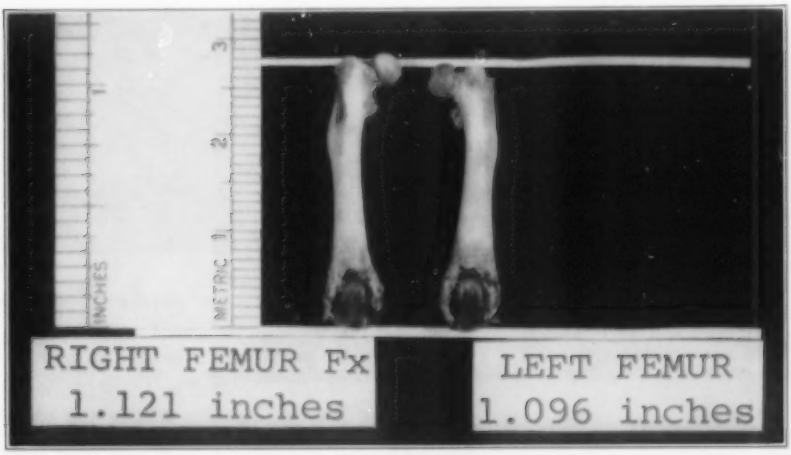

FIG. 1

Twenty-one days after fracture of the right tibia, the right femur of this rat has grown dramatically longer than the femur on the unfractured side.

On the other hand, when one compares the mean femur lengths of the fractured limbs to the mean femur lengths of the control animals (Tables III and IV), the results are quite different from those obtained from paired comparisons. On the third day after fracture, the femora of both fractured and non-fractured limbs of the experimental animals show statistically significant retardation of growth. This growth retardation is followed by femoral overgrowth that becomes significant in both fractured and non-fractured limbs on the twelfth day after fracture. The overgrowth period is then followed by periods with no significant differences except for the thirty-ninth day. One interpretation of this observation on the thirty-ninth day follows.

It has been noted that on many of the days after fracture comparisons with the paired extremities yielded significant differences, whereas comparisons with the extremities of the control animals on the same days often did not. This fact might lead one to infer that overgrowth in fractured animal limbs relative to unfractured limbs of control animals does not truly occur. Yet, we see on the fifteenth day, for example, that the mean lengths of femora on the fractured side, non-fractured side, and in controls were 1.036, 1.024, and 1.015 inches, respectively. How is it that 1.036 inches can be shown to differ significantly from 1.024 inches and yet not be different from 1.015 inches? The answer, of course, lies in the experimental design. In the first (paired) comparison, environmental and genetic differences between rats are cancelled out, each rat serving as its own control. In the second (group) comparison, genetic and environmental differences between rats add to the variability forming the basis for evaluating differences and prevent the difference, if real, from reaching statistical significance. A larger

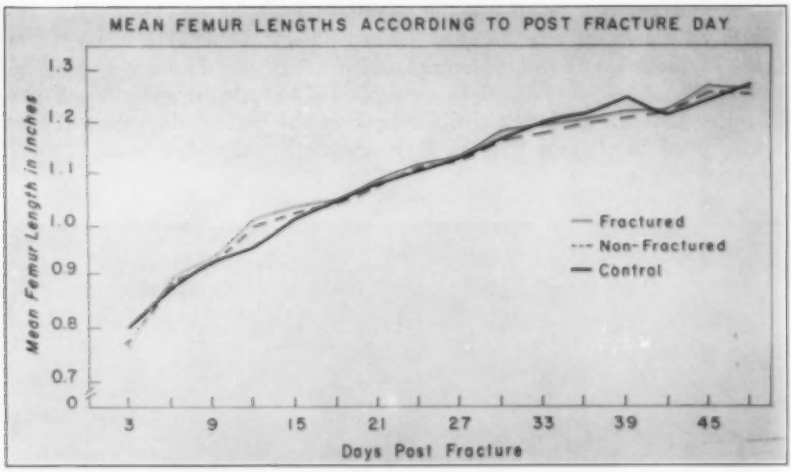

FIG. 2

The mean femur lengths in the control animals and in the fractured and non-fractured limbs of experimental animals have been plotted here. Increased femoral length is seen in the experimental animals over a rather brief period of time beginning about the sixth day after fracture and ending on about the eighteenth day. Femur length of the experimental animals is less on the third day and again on the thirty-third through the thirty-ninth day.

sample might demonstrate the reality of the apparently greater growth in both femora of the experimental group relative to the control group. The foregoing, of course, is an argument for the efficiency of paired comparisons whenever such a design is both reasonable and feasible.

The relative growth of femora in experimental and control rats is more readily appreciated when the mean femur lengths of control animals and the mean femur lengths of fractured and non-fractured limbs of experimental animals are plotted. Figure 2 represents a lot of the mean femur lengths used for calculating the values in Columns 3 and 4 of Table IV. It may be that the overgrowth phase is limited to that period extending from the sixth or ninth day to the eighteenth day after fracture. Although its significance is not immediately apparent, the period extending from the thirtieth day through the thirty-ninth is marked by less femoral growth in the experimental than in the control animals. These differences may be the result of sampling error in the control group rather than the result of truly slower growth rates.

In Figure 3 the mean differences in femur length of Group B (tibia fractured and femur length measured) are plotted against the mean differences in vascular volume of Group A animals (tibia fractured and plastic injected). Each dot represents the mean difference in the two variables in the sample of Group A and B sacrificed on the same day after fracture. No obvious association can be seen. A correlation analysis of the data corroborated this impression (correlation coefficient = .10; P greater than .5).

DISCUSSION

Careful consideration of the data obtained in this experiment leads one to make several inferences regarding skeletal growth in paired fractured and non-fractured hind limbs of experimental rats.

First, the demonstration of femoral overgrowth when the trauma is limited to the tibia suggests that the factor or factors leading to these growth changes

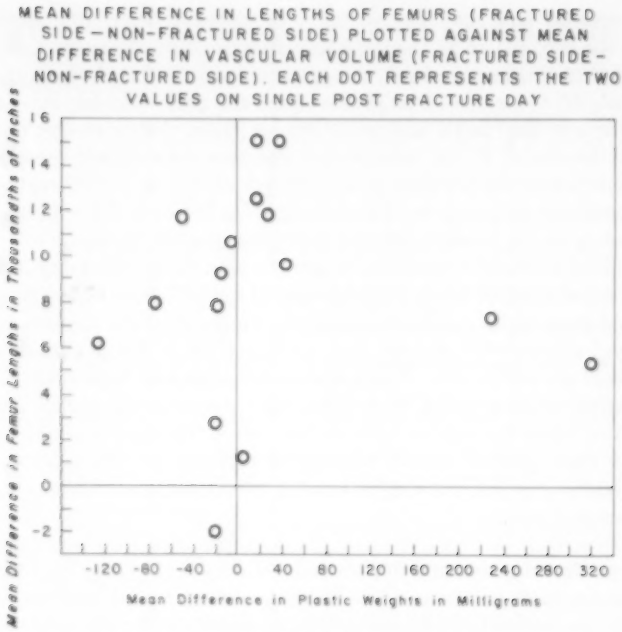
MEAN DIFFERENCE IN LENGTHS OF FEMURS (FRACTURED SIDE—NON-FRACTURED SIDE) PLOTTED AGAINST MEAN DIFFERENCE IN VASCULAR VOLUME (FRACTURED SIDE—NON-FRACTURED SIDE). EACH DOT REPRESENTS THE TWO VALUES ON SINGLE POST FRACTURE DAY
Mean Difference in Femur Lengths in Thousandths of Inches
16
14
12
10
8
6
4
2
0
-2
-120 -80 -40 0 40 80 120 160 200 240 280 320
Mean Difference in Plastic Weights in Milligrams

FIG. 3

When the mean differences in femoral length are plotted against the mean differences in limb plastic weights, there appears to be minimum association. A correlation analysis corroborated this impression (correlation coefficient = .10; P greater than .5).

are regional in effect and are not limited to the fractured bone. This observation is contrary to the conclusions of earlier writers but is compatible with present-day knowledge of vascular phenomena after fracture, which have been shown to involve the entire traumatized limb.

Second, there appears to be no relationship between long-bone overgrowth and vascular-bed hypertrophy after fracture, as measured by the plastic injection technique. On the other hand, other work has shown that vascular-bed hypertrophy in infant rats is much less marked than that in senile or adult animals [15]. This is probably due in part to the grossness of the technique, which is relatively less effective in smaller rats, and in part to the greater resistance to stretch possessed by vascular beds in younger animals. In any case, the failure to demonstrate a relationship between long-bone overgrowth and vascular-bed hypertrophy does not rule out the possibility that other vascular phenomena play a role in the growth changes. In earlier work with dogs as the experimental animal [19], one of us was able to demonstrate dramatic arterial-flow changes in the period after fracture. Immediately after fracture of the tibia in the dog, a marked increase in arterial flow occurs into the traumatized limb. At the same time the fractured limb is dilating, the opposite, untraumatized limb shows a dramatic decrease in arterial flow.

Although the metabolic consequences of these arterial-flow changes are unknown at the present time, it seems reasonable to assume that increased blood flow into a part might lead to epiphyseal stimulation with long-bone overgrowth [3,9,20]. Comparison of the femoral lengths of control animals with those of the fractured limb suggests that the overgrowth response is confined to a limited interval in the period after fracture. More recent work suggests that the

increased arterial flow may persist for a considerable time and appears to be present in the dog as late as the sixth day after fracture. There is some evidence to indicate that these arterial-flow changes extend into the ninth day in the rat. Earlier work [15,16,18] by one of us showed that the peak increase in vascular-bed volume occurs in the adult and senile rat on about the ninth day and appears to subside thereafter. If the arterial-flow changes are primarily responsible for growth stimulation, the presence of overgrowth as late as the fifteenth day after fracture forces one to conclude that there is a lag between the appearance of the factors leading to the overgrowth and the actual growth changes.

The initial bilateral retardation of growth seen at the third day in both fractured and non-fractured limbs of experimental animals may represent a reaction to increased amounts of cortisone liberated as a result of the trauma of fracture. Hillman and others [10,12,14] showed that cortisone has a definite inhibitory effect on epiphyseal growth in rats. Perhaps also of significance here is the decrease in weight-bearing stresses to the hind limbs that occurs in the period immediately after fracture, when the rats are notably less active. This factor might be expected to play an even greater role in two-legged animals, in which fracture of one lower extremity may prevent weight-bearing to any degree on either the fractured or non-fractured side.

The occurrence of overgrowth on the non-fractured side is of great interest and suggests that the overgrowth phenomenon may be, in part, the result of some general factor, such as the possible liberation of increased amounts of growth hormone in the period after fracture. This problem will be the subject of a later study.

The data for the terminal sacrifice day (forty-eighth day after fracture) do not provide an unequivocal answer to the question of whether the femora on the fractured or non-fractured side are longer or shorter than the femora in control animals. Certainly, the figures do not argue for any striking differences. Perhaps some mechanism exists whereby femur length is equalized by the completion of growth. Information concerning this question would seem to be of considerable clinical importance and is being investigated experimentally at this time.

CONCLUSIONS

1. The factors leading to long-bone overgrowth after fracture of the tibia in the growing rat are partly regional in effect and produce overgrowth in the femur of the same limb.

2. As evaluated by the plastic injection technique, vascular-bed hypertrophy after fracture does not appear to be related to the overgrowth phenomenon in the rat. On the other hand, it is possible that arterial-flow changes after fracture may play a part in the production of the growth alterations demonstrated in this experiment.

3. Immediately following fracture of one tibia in the immature rat, femoral growth is temporarily retarded on both fractured and non-fractured sides. This is followed by a period in which both fractured and non-fractured limbs show overgrowth. This femoral overgrowth is significantly greater in the fractured limb than in the non-fractured limb. Growth retardation of the unfractured side did not seem to contribute significantly to the observed differences.

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The Treatment of Irradiation Fracture of the Femoral Neck

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Spontaneous fractures of the femoral neck, secondary to the effects of irradiation, were first reported in the American literature in 1936 by Dalby, Jacox, and Miller. After studying their fourteen patients they concluded that roentgen therapy may, in some way, produce sufficient osteoporosis to allow spontaneous fracture to occur and that changes suggesting partial reduction of the blood supply to the femoral head occur in some patients. They remarked that obliterative endarteritis may be a factor in the production of these lesions.

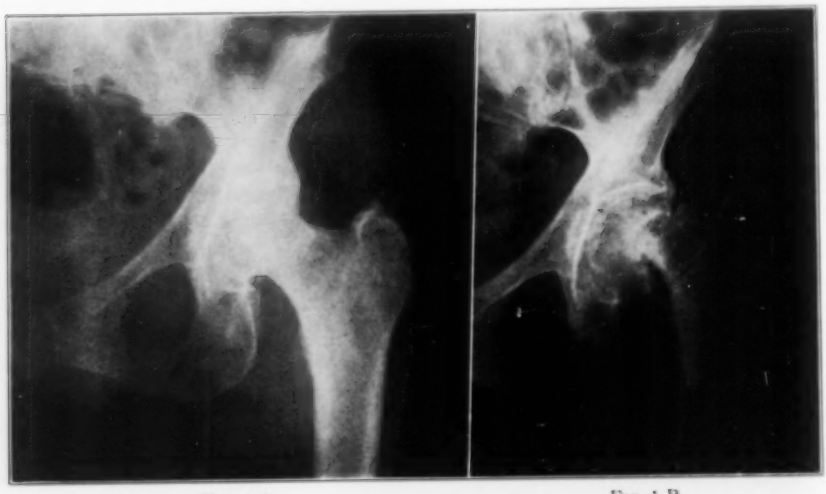

FIG. 1-A

FIG. 1-B

Fig. 1-A: Roentgenogram, made one month after the onset of pain in the left groin and anterior part of the thigh, shows a varus fracture of the left femoral neck with minimum displacement two years after irradiation therapy (Type I fracture).

Fig. 1-B: Roentgenogram made nine months after the onset of pain (Type III fracture). The patient was treated with crutches and non-weight-bearing.

Since this report more than 120 cases have been recorded. In 1947, Stampfli and Kerr reported twelve patients, ten of whom are included in the series now being reported. After analyzing the irradiation therapy received by their patients, these authors suggested that osteoporosis may result from vascular absorption and osteoclastic activity and that normal recovery is impeded by death of osteoblasts. They commented further that the cellular necrosis may be a direct effect of the radiation on the cells and that necrosis secondary to vascular occlusion does not occur frequently since vascular changes have not been observed consistently in the recorded histological studies. Although internal irradiation in dogs with radioisotopes has been observed to produce vascular occlusion in the absence of endarteritis [5], there is as yet no evidence that external irradiation, as

FIG. 1-C

Roentgenogram, made seven years after the onset of pain in the left hip, shows shortening and questionable union between the femoral head and the lesser trochanter. The left hip was clinically stable. The patient walked with one crutch and wore a shoe lift. Note the varus deformity of the right femoral neck which had developed without pain.

used in the treatment of carcinoma of the uterine cervix, produces occlusive vascular changes in the bone of the region irradiated, unless the dosage exceeds that ordinarily used (Fig. 2-D).

Bonfiglio enlarged the series reported by Stampfli and Kerr in 1952 to twenty-five, stressing the pathological changes in these irradiation fractures. Basing his opinions on nine biopsies of the femoral neck and head, he suggested that irradiation fractures represent stress or fatigue fractures through a subcapital zone of osteoporosis produced by irradiation, substantiating Stampfli and Kerr's opinions. He concluded that, in the usual dosage range, osteoporosis, not necrosis, is the primary effect of irradiation on the femoral neck and that the circulation to the femoral head is not appreciably impaired. Therefore, the occurrence of aseptic necrosis in these fractures is rare.

In 1945, Heyman reported on one patient with bilateral irradiation fractures which were treated successfully by internal fixation. Stephenson and Cohen, in 1956, presented the results of treatment of twenty-one fractures in seventeen patients observed over a thirteen-year period. In three of their patients, study of histological material corroborated the previous finding that osteoporosis is a predominant feature in the production of the fracture. It was their conclusion that the prognosis was favorable but that no specific line of treatment is applicable to these fractures. In 1961, Bickel and associates reported on nineteen patients with twenty-four fractures. Thirteen of these healed with non-operative treatment; eleven were treated surgically. The authors stressed that these fractures showed a strong tendency to heal even when the femoral head was in varus position and treatment was no more than protected weight-bearing with crutches.

The present paper concerns the results of treatment in the twenty-five patients previously reported by Stampfli and Kerr and by Bonfiglio, and in

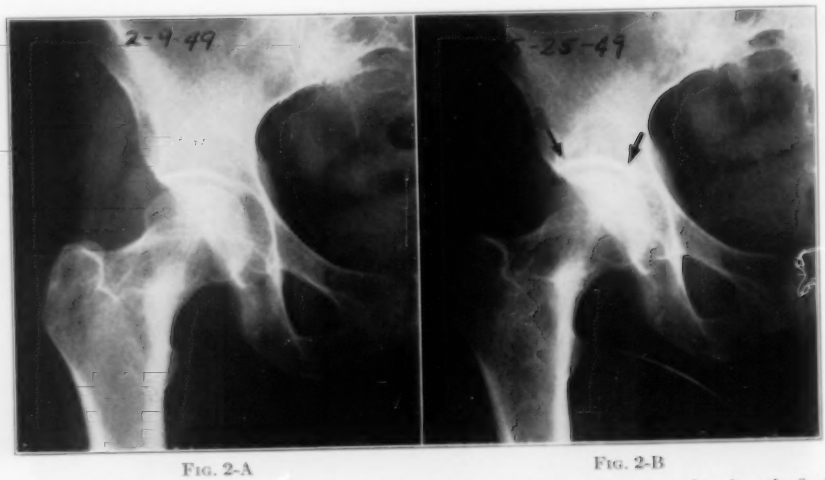

FIG. 2-A FIG. 2-B

Fig. 2-A: Roentgenogram shows osteoporosis of the acetabulum eleven months after the first course of irradiation and shortly after completion of a second course for metastatic disease.

Fig. 2-B: Roentgenogram, made after a fall on the right knee, shows a segmental acetabular fracture (arrows).

FIG. 2-C FIG. 2-D FIG. 2-E

Fig. 2-C: Roentgenogram, made after a third course of irradiation for metastases eighteen months after the original irradiation, shows an increase in bone density and fragmentation of the acetabulum.

Fig. 2-D: Roentgenogram, made twenty-nine months after original irradiation therapy, shows necrosis and flattening of the femoral head.

Fig. 2-E: Roentgenogram, made thirty-six months after original irradiation therapy and seven months after mold arthroplasty, shows the persistence of the acetabular fragment.

(Figs. 2-A, 2-B, 2-C, and 2-D are reproduced from the Pathology of Fracture of the Femoral Neck Following Irradiation by M. Bonfiglio. Am. J. Roentgenol., **70**: 449–459, 1953. Courtesy Charles C. Thomas, Publisher.)

nineteen additional patients. For a more detailed report on the irradiation therapy used in this series and for a complete evaluation of the pathological changes seen in these fractures, reference should be made to the original articles [2,6].

CLINICAL MATERIAL

From 1931 to 1959, 2,612 patients received pelvic irradiation for carcinoma of the uterine cervix at the State University of Iowa Hospitals; forty of these patients had fractures of the femoral neck, an incidence of 1.5 per cent. Four

FIG. 2-F

Roentgenogram, made nearly ten years after surgery, shows complete healing of the acetabular segment.

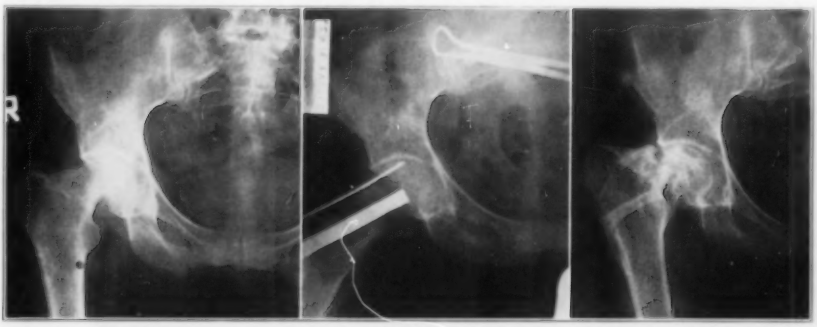

FIG. 3-A FIG. 3-B FIG. 3-C

Fig. 3-A: Roentgenogram, made two years after irradiation therapy, shows a varus fracture of the right femoral neck (Type III fracture).

Fig. 3-B: Roentgenogram, made at operation, shows marked distraction of the fracture fragments secondary to manipulative reduction and insertion of a Smith-Petersen nail. The tibial-bone graft has not yet been inserted.

Fig. 3-C: Roentgenogram, made after removal of the Smith-Petersen nail six months after operation, shows the fractured tibial-bone graft and recurrence of the varus deformity.

other patients with post-irradiation fractures diagnosed at this institution had received irradiation elsewhere. Follow-up in forty of the forty-four patients was long enough to establish the definitive result with respect to failure or bone union. Sixteen of the forty patients had bilateral fractures (an incidence of 40 per cent), making a total of fifty-six fractures treated.

The average age of the patients was 58.5 years at the time of irradiation. The average irradiation dose was approximately 3,600 r (parametrial dose), the

FIG. 4

Roentgenogram, made twelve years after a Lorenz osteotomy of the right hip, shows necrosis of the femoral head. There is a healed varus fracture of the left femoral neck, seven years after the insertion of an autogenous tibial-bone graft (Type I fracture).

largest dose being 4,235 r. The average interval from irradiation to the onset of pain in the hip was 36.6 months (three to 240 months) and from the onset of pain to diagnosis, three months. Forty-six surgical procedures were performed: thirty-six as primary treatment and ten because of failure or complications of the first procedure. The average follow-up of these patients was 6.9 years. The range of follow-up was from six months to fifteen years. Patients with hip fractures who had had pelvic irradiation but who also had an injury preceding the onset of pain were not included unless the trauma was minimum.

SYMPTOMS AND SIGNS

The presenting complaint was usually spontaneous onset of pain in the groin and medial portion of the thigh. Initially the physical examination often revealed nothing more than restriction of internal rotation of the affected hip, and the roentgenograms appeared normal in some instances. Subsequently, a change in bone density was noted at the inferior aspect of the femoral neck, denoting an early varus or adduction type of fracture (Fig. 6-A). The fracture line, or change in density, extended superiorly and laterally with complete displacement of the fracture resulting in some cases (Figs. 1-A, 1-B, and 1-C). The displaced fractures resembled the traumatic adduction fractures of the femoral neck seen in patients who have not received irradiation.

Along with changes in the femoral neck, acetabular changes may be noted. These changes are characterized by marked osteoporosis and occasionally fracture of the acetabulum (Figs. 2-A through 2-E), and the changes may be confused with metastatic lesions. It is important to recognize the acetabular changes for what they are so that additional irradiation will not be given. All of the acetabular defects in this series healed spontaneously, and in none of the patients did acetabular or femoral-head metastases develop (Fig. 2-F). In two patients who had received a second course of irradiation after onset of hip pain, necrosis of the femoral head occurred; in one of the patients, necrosis was proved by biopsy (Fig. 2-D).

There was an average delay of three months between the onset of pain and the diagnosis of the fracture. In this series there was no definite correlation of the delay between onset and diagnosis with the type or result of therapy.

Two patients in this series had moderately severe varus deformities of the femoral neck which were secondary to fracture but were only discovered because of routine follow-up roentgenograms (Figs. 1-C and 6-C).

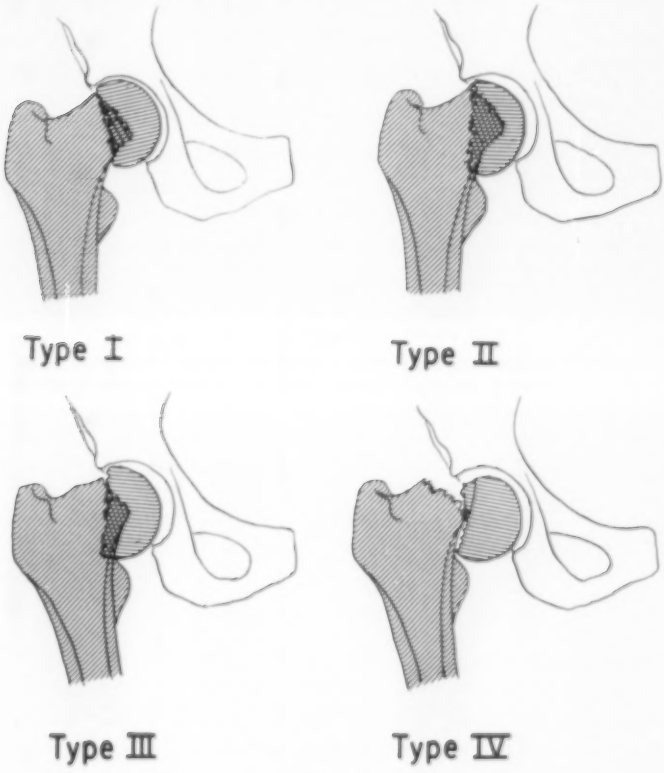

FIG. 5

The types of fracture.

RESULTS OF THERAPY

There were seven methods of primary therapy used to treat the patients in this series: no treatment, non-surgical measures (crutches or bedrest), internal fixation, bone-grafting (with and without additional fixation), osteotomy, arthroplasty, and the insertion of a prosthesis. Table I lists the modes of therapy and the results. In the grading of the results, a fracture which resulted in solid union was considered satisfactory. When reconstructive procedures were used as primary therapy, a satisfactory result was a painless hip with function adequate for the needs of the patient. The following factors were considered in the evaluation of the results of reconstructive procedures: pain, gait, deformity, range of motion and function with respect to work, dressing, walking, sitting, bathing, stair-climbing, picking up and carrying objects, and riding in a car.

In Table I, it should be noted that there were eleven satisfactory and nine unsatisfactory results in the patients who received no treatment or non-surgical treatment. Special note should also be made of the nearly total lack of success

TABLE I

RESULTS OF PRIMARY TREATMENT OF IRRADIATION FRACTURE OF THE FEMORAL NECK

Treatment	Results	
	Satisfactory	Unsatisfactory
None	3	4
Non-surgical	8	5
Internal fixation	5	2
Bone-grafting	14	5
Osteotomy	1	6
Cup arthroplasty	1	0
Femoral-head prosthesis	2	0
	34	22

TABLE II

RESULTS OF TREATMENT OF IRRADIATION FRACTURES WHEN COMPARED WITH THE SEVERITY OF DISPLACEMENT AT THE TIME OF PRIMARY TREATMENT LISTED AS SATISFACTORY AND UNSATISFACTORY

Treatment	Type I		Type II		Type III		Type IV	
	Satisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Satisfactory	Unsatisfactory
Non-surgical	1	1	1	2	2	1		2
Internal fixation	2		2			1		
Bone-grafting	5		2	1	4	1	1	
Osteotomy				2				
Cup arthroplasty							1	
Femoral-head prosthesis							1	
	8	1	5	5	6	3	3	2

after osteotomy. Ten other surgical procedures in addition to those listed in Table I were performed for failure of the primary treatment: three cup arthroplasties, five bone-grafting procedures, one osteotomy, and one internal fixation.

Table II attempts to show the relation of results of therapy to the type of fracture based on available pretreatment roentgenograms. A Type I fracture is represented by a slight varus deformity (Fig. 4), and a Type IV fracture by one with complete displacement (Fig. 8-A). Type II and Type III fractures represent gradations of severity of varus of the femoral neck between I and IV. From Table II it can be seen that the only unsuccessful result of treatment of a Type I fracture occurred after non-surgical treatment. Reconstructive surgery and bone-grafting procedures were used in six of the nine Type III and Type IV fractures in which satisfactory results were obtained (Fig. 5). Correlation of the type of the fracture with the results of treatment cannot be made satisfactorily because the more severely displaced fractures were usually treated by bone-grafting and internal fixation or by reconstructive procedures. Only five of the fourteen Type III and Type IV fractures were treated by non-surgical means; in three of these the results were unsatisfactory.

The average time of healing in those fractures treated by bone-grafting or internal fixation was six to nine months—the longest time, one year; and the shortest, three months. Non-surgical treatment with crutches required a longer period of time for healing, averaging slightly less than one year. It is important to note that after surgical fixation, the patients were routinely asymptomatic, whereas

FIG. 6-A

Case 1. Roentgenogram shows a varus fracture of the right femoral neck six years after irradiation and one month after onset of pain (Type I fracture).

FIG. 6-B

Roentgenogram, made three months after internal fixation and four months after the onset of pain, shows satisfactory healing of the fracture.

those treated with crutches continued to have pain, sometimes for several months.

Failure of healing was due to operative difficulties in three patients treated by internal fixation and internal fixation with bone-grafting. These operative difficulties consisted in poor or improper placement of the tibial-bone grafts and manipulation of Type III and Type IV fractures, with distraction of the fracture fragments (Figs. 3-A, 3-B, and 3-C). Aseptic necrosis resulted in four hips after treatment of the fracture by osteotomy (Fig. 2-D). One postoperative infection

FIG. 6-C

Roentgenogram, made fifteen months after fixation of the right femoral neck and nine months after onset of pain in the left hip, shows healed fractures of both femoral necks (left hip, Type II fracture).

occurred in a patient who had had two previous surgical procedures on the same hip.

DISCUSSION

Definite or dogmatic conclusions based on a small series with such a wide variety of therapy would be unwarranted. However, certain clinical points of interest can be discussed. Presentation of the following three case reports will illustrate some of these points.

CASE 1. N.M., a woman, sixty-seven years old, was given 4,000 r (parametrial dose) for epidermoid carcinoma of the uterine cervix. Six years later she noted the spontaneous onset of pain in the right groin and anterior portion of the thigh. One month later the diagnosis of irradiation fracture of the hip was made (Fig. 6-A), and a Smith-Petersen nail was inserted (Fig. 6-B). Postoperatively, the patient walked with crutches on a non-weight-bearing regimen. Two months after operation, graduated weight-bearing was started, and four months after operation, full weight-bearing was initiated. At this time, the patient went on a prolonged vacation to the West Coast. Two months later, six months after operation, she noted pain in the left hip and resumed crutch-walking on her own initiative, protecting the left hip. The pain disappeared in two and one-half months and the crutches were discarded, again on her own initiative. Two weeks later, nine months after her operation and three months after onset of pain in the left hip she was examined, and function of both hip joints was excellent. Roentgenograms, made fifteen months after operation and nine months after onset of symptoms in the left hip, revealed healed fractures of both femoral necks with varus deformities (Fig. 6-C). Four years after operation, the patient was still asymptomatic, doing her own housework.

CASE 2. E.B., a woman, fifty-six years old, was given 4,126 r to the mid-line of the lower portion of the abdomen for recurrent carcinoma of the right ovary. Three months after completion of the therapy, she noted spontaneous pain in the right groin and anterior portion of the right thigh. Roentgenograms made six weeks later revealed a varus fracture of the right femoral neck (Figs. 7-A and 7-B). The fracture was treated by internal fixation with a Smith-Petersen nail, and autogenous tibial bone was inserted in a biopsy channel. The patient was allowed to walk with crutches in two months on a partial weight-bearing regimen and to resume full weight-bearing seven months after operation. On her last visit, nine months after operation (Fig. 7-C), the patient

FIG. 7-A

FIG. 7-B

Fig. 7-A: Case 2. Anteroposterior roentgenogram of the right hip, made six weeks after the onset of pain, shows a varus fracture of the femoral neck (Type I fracture).

Fig. 7-B: Roentgenogram of the right hip in the lateral projection made at the same time as Fig. 7-A.

Fig. 7-C: Roentgenogram, made nine months after operation, shows a Smith-Petersen nail and an autogenous tibial-bone graft in place. The fracture is healed.

(Figs. 7-A, 7-B, and 7-C are reproduced from The Pathology of Fracture of the Femoral Neck Following Irradiation by M. Bonfiglio, Am. J. Roentgenol., **70**: 449–459, 1953. Courtesy Charles C. Thomas, Publisher).

FIG. 7-C

was asymptomatic and hip motion was normal, except for a slight restriction of rotation. The patient died of metastases eighteen months after operation.

CASE 3. G.H., a woman, sixty-three years old, was given 3,969 r (parametrial dose) for epidermoid carcinoma of the uterine cervix. Four years later, she began to have pain, and a progressive deformity of the left hip, associated with a limp, developed over a period of nine to twelve months. No medical aid was sought. Ten years after irradiation therapy, the patient bumped her right hip and pain in the right groin and anterior part of the thigh developed. Roentgenograms of the right hip were reported as normal at that time, but an ununited fracture of the left femoral neck was noted. One month later, a varus fracture of the right femoral neck was seen on roentgenograms made because of the persistent pain. The patient was treated alternately with bedrest and crutch-walking for three and one-half months, at which time the pain had increased. The patient was then referred for orthopaedic consultation and roentgenograms revealed a displaced femoral-neck fracture of the right hip (Fig. 8-A). A long-stem femoral-head prosthesis was inserted. The patient was walking without support in three months and returned to work as a hotel maid. One and one-half years later (Fig. 8-B), the patient had symptoms referable only to the left hip. She did not desire reconstructive surgery on her left hip.

The non-surgical form of therapy cannot be recommended on the basis of this series of cases because of the obvious difficulty in predicting the outcome of conservative treatment (Fig. 1-C and Case 3, Fig. 8-A; Case 1, Fig. 6-C). Unless general medical conditions prohibit, some form of fixation or reconstruction is advisable in all cases.

Varus fractures with minimum to moderate displacement heal satisfactorily when treated by internal fixation *in situ* (Case 1, Figs. 6-A, 6-B, and 6-C). Strong manipulation to attain an anatomical reduction is not recommended because of the tendency of the varus position to recur and the risk of further damage to the

FIG. 8-A

Case 3. Roentgenogram made six months after the onset of pain in the right groin and anterior part of the thigh and ten years after completion of irradiation therapy. Note the ununited fracture of the left femoral neck (Type IV fracture).

blood supply to the femoral head (Figs. 3-A, 3-B, and 3-C). In fractures with more marked varus displacement, some manipulation may be required: under these circumstances one or two bone grafts should be added for support to aid healing (Case 2, Figs. 7-A and 7-B). In fractures with complete displacement, reconstructive procedures worked well in our series (Case 3, Figs. 8-A and 8-B).

Because of the high incidence of bilateral fractures, patients with one post-irradiation fracture should be followed closely for symptoms of a fracture on the opposite side. In this series, a Smith-Petersen nail was inserted in one patient's hip because of symptoms of fracture even though there was no roentgenographic proof of fracture.

CONCLUSIONS

1. Early *in situ* internal fixation or internal fixation with bone grafts is the procedure of choice in fractures of the femoral neck secondary to irradiation.

2. Reconstructive procedures, such as cup arthroplasty or insertion of a prosthesis, are effective treatment in selected cases.

3. Osteotomy is not applicable for primary treatment of this type of fracture.

SUMMARY

The treatment of forty patients with fifty-six post-irradiation fractures of the femoral neck is presented. Because of the difficulty in predicting the outcome of non-surgical therapy, some form of internal fixation or reconstructive procedure

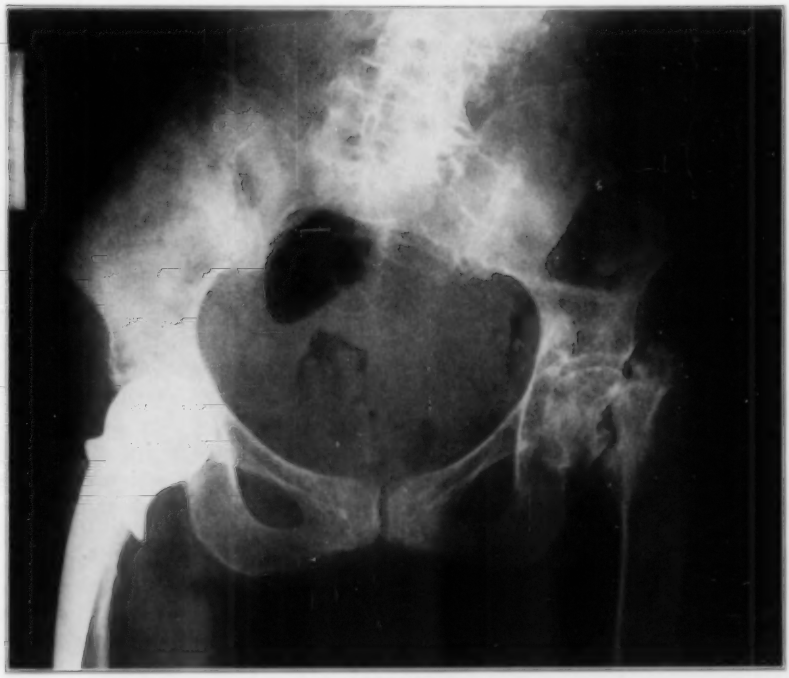

FIG. 8-B

Roentgenogram made twenty-one months after the onset of pain and fifteen months after the insertion of a long-stem femoral-head prosthesis.

is recommended in all patients when the fracture is diagnosed. The fixation should be performed *in situ* if feasible. If reduction is attempted, additional fixation with a bone graft is recommended. Osteotomy is not applicable for primary treatment of this type of fracture.

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Spondylolisthesis

Complete Slip Following the Gill Procedure: A Case Report

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In the treatment of spondylolisthesis there are conflicting opinions whether spine fusion or removal of the neural arch is the most effective. The case reported here is of interest because of the documented slipping of the vertebra after removal of the neural arch with recurrence of the patient's symptoms. Bosworth and associates stated that further slipping of the vertebra may occur after removal of the neural arch and argued that the neural arch prevents slipping and provides support for the spine. We also believe that removal of the arch weakens the involved area and that, if the arch is removed, spine fusion is indicated [1].

CASE REPORT

A sixteen-year-old boy had a history of spondylolisthesis of the fifth lumbar on the first sacral vertebra which had been asymptomatic until two years before he came under our care when low-back pain gradually developed. At that time a Gill procedure was performed. The operation left him free of pain for eighteen months, when walking produced dull aching in the back of both thighs which was relieved only by rest. There was no radiation of the pain below the knees and no paresthesiae, weakness, or bowel disturbance.

The general physical examination was within normal limits. The patient was short with no visible waist, and he had a marked lumbar lordosis. Palpation of the lumbosacral area revealed an area of tenderness paraspinally on the right at the level of the fifth lumbar vertebra. There was no radiation of pain into the lower extremity produced by pressure on this tender area. The ranges of back motion were: flexion to 45 degrees, without much lumbar motion; extension to 10 degrees; lateral flexion to 30 degrees, bilaterally; and rotation to 20 degrees, bilaterally. Straight-leg raising was limited to 45 degrees bilaterally.

The neurological examination showed all muscle groups to be of Grade 5, and sensation was intact throughout. The patellar reflex was + on the right and ++ on the left. The ankle reflex was absent bilaterally. Laboratory data were within normal limits.

Figure 1, a lateral roentgenogram of the lumbar spine prior to the Gill procedure, reveals spondylolisthesis of the fifth lumbar vertebra with forward displacement of this vertebra on the first sacral equivalent to one-half of the width of the centrum. Figure 2 shows complete displacement of the fifth lumbar vertebra in front of the sacrum two years after the Gill procedure.

TREATMENT

On July 26, 1960, under general anesthesia, a Hibbs-type spine fusion from the third lumbar vertebra to the sacrum was done, supplemented with bone grafts from the patient's iliac crest and from the bone bank. There was a large spina bifida of the sacrum, with the dura visible at the first and second sacral segments. On exploration, the body of the fifth lumbar vertebra could not be seen, but an unusually large portion of the sacrum, including the posterior part of the superior end-plate of the first sacral vertebra, was visible due to the forward slipping of the fifth and superincumbent lumbar vertebrae.

After the operation, the patient did very well. The sutures were removed one week after surgery; the wound healed *per primam*. The patient was fitted with a lumbosacral corset and was allowed to walk on the tenth day after operation. Roentgenograms obtained four months after operation revealed an apparently solid fusion (Fig. 3). The patient was relieved of pain at his last visit one year after operation. He was fully active and during the past six months he had walked several miles to school each day and had participated in all sports. Flexion-extension roentgenograms were not made because of the excellent clinical course and the large mass of bone that was visible on the lateral roentgenogram made four months after operation.

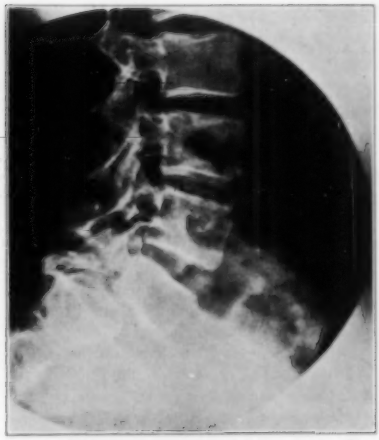

FIG. 1

FIG. 2

Fig. 1: Lateral roentgenogram of the lumbar spine prior to the Gill procedure shows spondylolisthesis of the fifth lumbar on the first sacral vertebra.

Fig. 2: Lateral roentgenogram of the lumbar spine shows complete slipping of the fifth lumbar vertebra over the anterior prominence of the sacrum two years after the Gill procedure.

Fig. 3: Lateral roentgenogram of the lumbar spine four months postoperatively revealing evidence of solid fusion.

FIG. 3

SUMMARY

A case is presented in which documented slipping of the vertebra in spondylolisthesis after removal of the neural arch occurred. Successful treatment consisted in spine fusion from the third lumbar vertebra to the sacrum.

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THE VIRGINIA STATE ORTHOPAEDIC SOCIETY

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The Virginia State Orthopaedic Society held its Annual Spring Clinical Meeting as a guest of the Tidewater Orthopaedic Group in Norfolk, Virginia, on April 14 and 15, 1961. The following clinical papers were presented:

Fat, Bone Marrow, and Muscle Emboli Following Trauma. Dr. Arthur Kirk [1] reviewed the literature on the occurrence, pathological physiology, and pathogenesis of pulmonary and cerebral emboli of various types after trauma. It was pointed out that in many patients there will be a shower of small pulmonary emboli following acute trauma. Such emboli consist primarily of large fat droplets from the bone marrow. These will usually appear from twenty-four to seventy-two hours after injury and be manifested clinically by some dyspnea, and a roentgenogram of the chest will show spotty cloudiness in the peripheral lung fields. These pulmonary emboli are frequently misdiagnosed as virus pneumonia. Most patients survive this insult, but in approximately five to seven days they may become confused, dyspneic, and apprehensive, and may show generalized signs of toxemia. This is due to emulsification of the fatty acids in the fat droplets, which produces areas of focal necrosis in the lungs and a patchy or diffuse bronchopneumonia. Unless treated vigorously this pneumonia will result in death. Two fatal cases were presented with microscopic emboli in the lungs, consisting of fragments of muscle, fat, and one small island of cortical bone, embolic from a fracture of the humerus.

An Analysis of 100 Consecutive Closed Fractures of the Tibial Shaft. Dr. Henry J. Waive [2] compared fifty-five fractures treated by closed reduction and immobilization in a plaster cast with forty-five fractures treated by open reduction and internal fixation. In the closed group, the average healing time was 4.8 months, with two cases of non-union and nine cases of delayed union. In the open group, the average healing time was 5.2 months, with two cases of non-union and ten cases of delayed union. The author considered the healing time as the period between the fracture and the time when immobilization was discontinued and the patients began walking, using two crutches. No serious complications were due to operative treatment, and only the comminuted fractures demonstrated a significantly prolonged healing time and greater incidence of complications. Fractures of the lower third of the shaft had a higher incidence of non-union and delayed union than fractures seen elsewhere in the tibia. Displacement of the fracture fragments prolonged healing time. It was suggested by the author that six months be considered as the outside limit for normal healing time in a closed fracture of the tibial shaft.

Hip Fusion Using the Schneider Nail. Dr. Melvin H. Kunkle [3] reported the results in eleven hip-fusion operations using the Schneider intramedullary nail for internal fixation. Bone union was reported to have occurred in seven of the eleven cases, but in several reoperation was required for various reasons. The author felt that the procedure offered many advantages over other types of hip-fusion techniques, principally the avoidance of a cast following surgery. The discussors felt, however, that the procedure was subject to too many technical difficulties to justify its use except in very unusual circumstances.

The guest lecturer was Dr. Harrison L. McLaughlin [4]. In his first lecture, **Lesions of the Shoulder,** Dr. McLaughlin discussed a wide variety of soft-tissue lesions, recounting his experience over the past twenty years. He suggested that the name *bursitis* be discarded, as the bursitis is a result of other lesions rather than a true clinical entity. He divided soft-tissue lesions of the shoulder into three groups: frozen shoulder, painful calcific deposits, and mechanical derangements, such as cuff tears.

No cuff tears had been observed in over 300 cases of frozen shoulder, and no calcific deposits were seen in cuff tears. A frozen shoulder frequently follows prolonged dependency of the arm.

The cause of the frozen shoulder may not necessarily be in the shoulder girdle: the examiner should look for possible causes elsewhere in the body. The frozen shoulder is a stigma of emotional tension. Pain from disease in the shoulder joint itself is rarely referred past the wrist, whereas cervical-nerve-root pain extends into the fingers. Bursitis *per se* does not cause a frozen shoulder. Adhesive capsulitis is a result, not a cause, of the frozen shoulder. Ten per cent of cases of the frozen shoulders that have been operated on have shown proliferative synovitis; 90 per cent have

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3. 108 Fort Lane, Portsmouth, Virginia.
4. 180 Fort Washington Avenue, New York 32, N. Y.

shown no remarkable histological changes. The pathogenesis of the frozen-shoulder syndrome is a loss of elastic tissue in the tendinous and ligamentous tissues of the shoulder girdle.

The diagnostic signs of cuff tears were described as displaced tuberosity of the humerus, positive arthrogram, atrophy of the supraspinatus and infraspinatus muscles, and dysfunction of the cuff. The author believed that 50 per cent of cuff tears would respond to conservative treatment.

Parosteal Sarcoma of Bone. Dr. John Thiemeyer [5] presented a twenty-minute movie of the case of a white woman, forty years old, with a parosteal sarcoma of the lower portion of the femur. She was treated with disarticulation of the hip. The movie included the physical findings, the surgical procedure, the gross and microscopic findings, and the rehabilitation of the patient, following surgery, with a prosthesis. This was followed by a discussion of parosteal sarcoma in which the principles of treatment were discussed.

A New Functional Brace for the Upper Extremity. Dr. Roy M. Hoover [6] demonstrated the principles and use of functional braces for the upper extremity. Dr. Hoover stressed that the rehabilitation of patients with motor paralysis of the upper extremity is a team approach of physician, prosthetist, and occupational therapist. The new functional brace is useful in poliomyelitis, peripheral nerve injuries, and cervical-cord lesions.

Anorganic Bone. Dr. Ira M. Cantin [7] reported the use of anorganic bone (ethylene diamine treated bone) in a case of a very large giant-cell tumor of the upper third of the tibia in a Negro man, forty-two years old. Complete curettage of the tumor was followed by packing with anorganic bone. Two years after surgery the patient had an excellent end result.

Ankle Injuries. Dr. Harrison McLaughlin [4], in his second lecture, stressed that an orthopaedist must obtain perfect anatomical restoration after injuries of the ankle to obtain good end results. Healing after trauma to the calcaneofibular ligament may cause stenosing tenosynovitis of the peroneal tendons which can be relieved by opening the tendon sheaths. Severe ankle sprains should be immobilized in a walking cast. Such injuries may have rupture of the tibiofibular ligaments without fractures. Fractures of the lateral malleolus may be associated with invagination of the torn medial tibiocalcaneal ligament into the medial joint space of the ankle mortise. This can only be relieved by open surgery to replace and repair the torn ligaments. In fractures of the posterior lip of the tibia, if the fracture involves 10 per cent of the articular surface, the end result will be good; if 30 per cent of the articular surface is involved, 2 per cent of the fractures will slip following closed reduction. All fractures with more than 30 per cent of the articular surface involved should have open reduction. In isolated fractures of the medial malleolus, if the fracture is below the level of the top of the talus, fibrous union will not be harmful. If the fracture is at the level of the articular surface of the talus, then open operation should be done, and the author stressed that operation should occur early before swelling has developed.

5. Medical Towers, Norfolk, Virginia.
6. Woodrow Wilson Rehabilitation Center, Fishersville, Virginia.
7. 132 West York Street, Norfolk, Virginia.

CORRECTION

In the article Tissue Reactions to Metals — The Influence of Surface Finish by Jonathan Cohen, M.D. in the July 1961 issue on page 688, the last sentence of the first paragraph under the heading *Materials and Methods* should read "The thickness of the surface finish, measured with a profilometer with fine stylus, was, for the sand-blasted finish, thirty to fifty-five micro-inches, for the vapor-blasted finish, forty to fifty micro-inches, and for the electropolished finish, twenty to twenty-five micro-inches.

VERNON P. THOMPSON

1898–1961

Few men have influenced the progress of orthopaedic surgery as did Vernon Thompson. He was a skilled surgeon, a thoughtful and critical scholar, and, above all, a teacher. Throughout his life the training of young orthopaedists took precedence over all other activities, even to the detriment of his own welfare.

Born in Colton, California, on December 7, 1898, his premedical training was at Stanford University. There he was almost lost to orthopaedics because Dr. Arthur Meyer's enthusiastic insistence that a student do not ask but go into the dissection room and find out for himself, led Dr. Thompson to the point of considering anatomy rather than medicine as a career. In 1917 he spent a year of officer's training with the United States Army in Georgia. Graduated at Harvard Medical School in 1923, he interned at Stanford but returned to Boston for his specialty training in the Massachusetts General Hospital and the Children's Hospital.

In 1925 he married Frances Ewing of Portland, Oregon. He leaves his wife, a son, Vernon Ewing Thompson, an electronics engineer, a daughter, Miriam Thompson Romans, the wife of a pediatrician, and five grandchildren, all of Los Angeles.

His Boston experience led him to the support of Dr. Joel Goldthwait in the once famous but now forgotten battle of conservative treatment versus the quick scalpel and its unhappy corollary the "quick buck". This attitude carried into his work at Los Angeles Children's Hospital where he spent patient years at back-breaking research on the conservative treatment of scoliosis at a time when other men were saying "any scoliosis worth treating is worth fusing". This work is being carried on in several orthopaedic centers throughout the country, notably by Dr. Walter Blount, Dr. Albert Schmidt, Dr. John Moe, and Dr. Joseph Risser.

In spite of his conservative background it is of interest that he was the inspiration for some of the most radical surgical work done today: the extensive operations now being done by Dr. Vernon Nickel and Dr. Jacquelin Perry at Rancho Los Amigos Hospital, Downey, California, on patients with respiratory poliomyelitis who were formerly considered inoperable.

As Associate Professor of Orthopaedic Surgery at the University of Southern California, with his position as Senior Consultant at the Los Angeles County Hospital, he had a vast source of teaching material. His teaching was characterized by a keen perception of the superficial or thoughtless answer to which he gave no quarter. Dr. Jacquelin Perry writes, "His insistence on accuracy of thought and statements was a valuable challenge which few leaders have the courage to uphold and even fewer have the tact to get both colleagues and students to accept". He had an almost religious worship of the truth.

Leading a surgical conference he listened attentively to the discussion but was apt to close the meeting with a short remark, "Not one of you noticed the other hip!" Such a remark, leaving his audience with the feeling they had been knocked down, was made with a broad grin and a twinkle in his eye but was characteristic of his interest in the whole patient rather than a diseased part. This was an attitude he adhered to always.

He was a member of Nu Sigma Nu, an honorary member of Alpha Omega Alpha, winner of the Kappa Delta Award in 1951 for his work with Dr. Herman Epstein on traumatic dislocation of the hip (204 cases), and a member of the Editorial Board of The Journal of Bone and Joint Surgery. His own contributions constitute only a small part of his total bequest to orthopaedic surgery. The work of younger men whom he taught and inspired will have to be considered his personal addition to the fund of knowledge now available in his field.

He served in the Medical Corps of the United States Army in World War II, being discharged Lieutenant Colonel in 1945. Typical of his unusual courage was his comment in 1943, when Surgeon General Norman Kirk was planning to assign him as consultant in the European Theatre after he was found to have a supposedly fatal illness and was offered a medical discharge: "There is still a lot I can do for the army. Why don't you send me to a hospital equipped with elevators?" He was transferred from Ashburn General Hospital in McKinney, Texas, to the Army and Navy Hospital at Hot Springs National Park, Arkansas, where his family joined him. He served through the war and returned to private practice and his beloved students.

In 1952 he became Chief Consultant at Rancho Los Amigos Hospital, where he continued his study and teaching even after his confinement to a wheel chair and retirement from practice in 1954.

Elected President of the Western Orthopedic Association in 1952 he immediately turned to his primary interest, establishing a competitive presentation by resident surgeons of western universities. This half-day program and award still continues as the "Vernon Thompson Resident's Program" and has proved to be of unusual scientific value. He felt the young resident should be seen, known, and heard rather than being buried in the joint authorship "Prof. Someone, et al".

He was the doctor's orthopaedist. As my physician, I can bear witness to the fact that no one came to him seeking help without feeling that he had received the help he sought.

He loved to laugh at himself. His great joy and heartiest chuckle came when he found himself caught in error by one of his colleagues or students. He said of the Thompson "Z" nail which he devised early in the history of internal fixation of femoral-neck fractures, "This may not be the last word in hip pinning but at least it is the last letter".

With regard to his critical and often caustic comments when scientific truth had been ignored it has been said "He poured oil on the troubled waters but then he threw the match in even if he got burned himself".

His death on July 22, 1961, from uremia, will be felt throughout the medical world as the loss of a great friend and teacher.

H.E.C.

Book Reviews

SURGICAL ERRORS AND SAFEGUARDS. Ed. 5. Edited by Max Thorek, M.D. Philadelphia, J. B. Lippincott Company, 1960. $25.00.

This book has now reached its fifth edition, which in itself is an indication that the book has been well received by the medical public and is in enough demand to require another printing. This edition has been completely rewritten with the assistance of twenty-two collaborating authors. Two new chapters have been added, one on anesthesiology and one on cardiac surgery.

In general, the book is well written and fills a need for the practicing surgeon, the house officer, and the medical student. A great deal of pertinent information is given concerning the errors the surgeon may make and the methods of preventing them. Certainly many hundreds of lives would be saved and many thousands of patients would have fewer complications if the information collected in this book were known to all surgeons.

The chapter on anesthesiology and the chapter on cardiac surgery are both welcome additions to the volume, are well written, and add greatly to the value of this edition.

In general, the book accomplishes its purpose and that is to describe and discuss the errors that may befall the unwary surgeon and the means of preventing them. There are areas, however, where the statements of the authors would appear to be somewhat archaic and would definitely not agree with the thinking of most surgeons today. The proper use of parenteral-fluid therapy in preoperative and post-operative treatment is touched on only lightly, and statements recommending the use of glucose and saline solutions per rectum would no longer appear to be advisable with the present methods of treatment that are available. The intraperitoneal infusion of citrated blood suggested for the treatment of hemorrhage would appear to have little to recommend it in the light of present-day intravenous transfusions.

The discussion of congenital anomolies, such as pyloric stenosis, ignores many of the modern concepts of the disease especially the necessity for proper fluid therapy for these sick infants.

The criticisms of this book detract from its over-all value, but it is a worthwhile addition to the surgeon's library and should be read frequently by anyone engaged in the practice of surgery.

John H. Davis, M.D.

THE HAND. A Manual for the General Surgeon. Henry C. Marble, M.D. Philadelphia, W. B. Saunders Company, 1960. $7.00.

Surgery of the hand is not a specialty, but a field of special interest. Most of this interest has come from orthopaedic and plastic surgeons who have contributed much to the advancement of this field during the past two decades. General surgeons up to now have not shown a comparable interest, although in some areas, notably Boston, Massachusetts, the hand clinics have been under their supervision. Since 77 per cent of all injuries resulting in permanent partial disability occur in the hand or fingers, more emphasis on the training of the general surgeon along this line should result in better primary care.

Dr. Marble has apparently concluded that an elementary primer is now needed to help the general surgeon who may give this first surgical care. One might argue that this very basic approach has certain inherent dangers, but most surgeons, and even the trained medical corps men he wants to help, will realize that modern high-speed transportation has altered the old concept of surgery being done under less than ideal conditions. There are few places so remote medically that basic first aid treatment cannot be given and the patient transported to a center, where adequate facilities and personnel are available.

The text is assertedly based on the methods that Dr. Marble and his associates at Massachusetts General Hospital have used and found satisfactory. This is the book's weakness. Less than a dozen references appear in the 200 pages and only two of these from the period since World War II, during which the surgical literature has been almost surfeited on all phases of the injured or disabled hand.

Since 1946 there have been many books on the hand, listed as manuals or guides, published in the United States, England, Sweden, France, Germany, and one is even in press now in Brazil. All of these aim to give the surgeon, who first encounters the injured hand, a foundation upon which to build a plan of treatment. Most of these have accomplished their purpose; some were superb, all were timely.

This book should have been published twenty years ago; it would have been a timely introduction to the great field of surgery of the hand and would have given the inexperienced surgeon the fundamentals in simple form so that he would then be better able to understand the more detailed texts that have since been published.

Joseph H. Boyes, M.D.

TRAUMA IN THE AGED. Edited by Edgar M. Bick, M.D. With an Introduction by Robert H. Kennedy, M.D., New York, McGraw-Hill Book Company, 1960. $16.00.

Trauma in the Aged, edited by Dr. Bick, is thoroughly covered in the introduction by Robert H. Kennedy as "The Special Problem", in which Dr. Kennedy reveals his understanding of people, as well as the aged patient. The need to be a physician first and then a specialist is clearly presented.

Eighteen physicians of professorial rank (or its equivalent) have presented the subjects in detail. These subjects are logically grouped into five parts: (1) pathological physiology of the aged, (2) musculoskeletal trauma of the aged, (3) visceral trauma of the aged, (4) injuries to the aged somatic tissues, and (5) rehabilitation of the aged.

Each part read alone provides a complete coverage of the subject; however, since they are compiled into a book, avoidable repetitions are more evident. Collective editing would have made a more useful book.

Sound principles are emphasized throughout. Care and attention to detail is evident. It is distressing, however, to find the constant misspelling of the name of so prominent a physician as the late M. N. Smith-Petersen.

Although, according to its title, the main emphasis of the book is trauma in the aged, the material is definitely applicable to all ages.

Otto E. Aufranc, M.D.

STRUCTURE AND FUNCTION OF MUSCLE. VOL. III. PHARMACOLOGY AND DISEASE. Edited by G. H. Bourne. New York, Academic Press, 1960. $15.00.

This three-volume work under the well qualified editorship of Dr. Bourne fulfills a definite need to gather together in one place some of the highlights of current knowledge of muscle. There has been a marked increase in research interest in muscle in recent years with the consequence that the periodical literature dealing with this subject has expanded in logarithmic proportions. Until Dr. Bourne's book there has been no recent reference work to distill this large body of information.

Volume III deals with some aspects of the pharmacology, pathology (including histochemistry), nutrition, aging and post-mortem changes of skeletal, and in some chapters, cardiac and smooth muscle. These sections are written by active research workers; therefore, they are authoritative and reflect an intimate knowledge of problems and progress.

Volume III is the only one which attempts in any way to deal with the clinical aspects of muscle disease, and then only briefly. In thirty-three pages Dr. Ronald A. Henson summarizes some of the clinical aspects of the various myopathies; and, in the following chapter, Dr. John W. Walton discusses the genetic aspects.

The concluding chapter consists of a few summarizing comments on muscle contraction and relaxation by one of the most famous of all workers in the field of muscle research, Dr. Albert Szent-Györgyi.

There is a rather extensive bibliography which appears to be pertinent and reasonably complete.

This volume, along with its predecessors, will find its greatest usefulness in the hands of basic science research workers and teachers, particularly new-comers to the field who desire a reference work which covers the current knowledge of muscle in a reasonably comprehensive fashion. The clinician may find limited use for it but most of the chapters are too technical to hold his interest for long.

It is hoped that a work of similar scope and quality will shortly appear for the clinician.

Joseph W. Hess, M.D.

MASSAGE, MANIPULATION, AND TRACTION. Sidney Licht, Editor. New Haven, Elizabeth Licht, 1960. $10.00.

This book, the latest in the series on various aspects of physical medicine, deals with subjects which are somewhat controversial, but are among the oldest forms of treatment. Fourteen authors from the United States, England, and Europe contribute to this volume.

Part I consists of eight chapters on the physiologic effects of massage, on classic technique, and on massage of connective tissues.

Part II has three chapters which deal with manipulation of the spinal column and extremities as well as with stretching techniques.

Part III has two chapters devoted to traction, including the use of motorized devices.

Orthopaedists and others interested in physical medicine and rehabilitation will find this book not only interesting but informative. The authors appear to have been well chosen. Some aspects of the material are open to question, but even these may be worth considering and put to use in the light of our present knowledge. The material is presented in a straightforward manner without

unwarranted claims and without any embellishments which would only create more conflicts in our analysis of this aspect of physical medicine.

Donald J. Erickson, M.D.

SYNOVIAL JOINTS. THEIR STRUCTURE AND MECHANICS. C. H. Barnett, D. V. Davies, and M. A. MacConaill. Springfield, Illinois. Charles C. Thomas, 1961. $11.50.

I am enthusiastic in recommending this book because it will appeal to such a wide audience. For those interested in joints, from the seasoned orthopaedic surgeon down to the interested medical student, the book contains information too new to be in recent texts and yet so pertinent to the understanding of synovial joints that it may be classified as required reading. It covers subjects belonging for the most part to anatomical works, but equally apropos to physiological, biochemical, and a variety of other fields. This is yet another reason for my interest in this book since purely anatomical works tend to disregard these para-anatomical sidelights. Readers of this journal will recognize the contributions of MacConaill from his series of articles published about ten years ago on joint mechanics and allied subjects. But the contributions of Davies and Barnett, appearing for the most part in other journals, may not be so familiar. The collaboration of three seasoned investigators of the structure and mechanics of joints thus represents an authoritative portrayal of present views. However, this is not a textbook in the ordinary sense. For one thing, it reads too easily. For another, it treats of concepts rather than specifics. If you are interested in the hip, for example, you will not find a section devoted to the specific problems of that joint, and the index will direct you to several sections where the hip is used to exemplify a principle, without covering the subject *in extenso*.

This book, therefore is made for reading, not reference. As one reads, provocative applications of the data are sometimes mentioned in passing, but frequently I had to lay aside the book to follow my own thoughts which arose from the welter of suggestive information. The book is short and is divided into four sections: The Components, Biology, Mechanics, and Functions of Joints. Each part has appropriate chapters, for example, Metabolism and Nutrition, Evolution, Joint Position, Synovial Fluid, and Mechanical Efficiency, but surprisingly the unity of the material and its even treatment stand out rather than the logic of its compartmentalization. This book should be read by all orthopaedists and trainees. It would make an ideal gift.

Jonathan Cohen, M.D.

SUBTROCHANTERIC OSTEOTOMY

Radiographs on Kodak Medical X-ray Film; surgery photographed on Kodak Ektachrome Film

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Figure 1: Radiograph and accompanying photograph demonstrate multiple congenital defects, both extremities. Note marked coxa vara, left.

Figure 2: Curvilinear incision over left trochanteric region.

Figure 3: Outline of "Z"-cut osteotomy. Osteotome at distal end of long arm of "Z".

For additional photographs of surgery and final radiograph, turn page.

FIGURE 1.

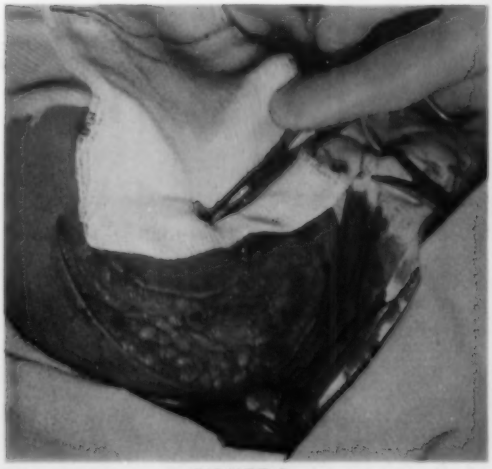

FIGURE 2.

FIGURE 3.

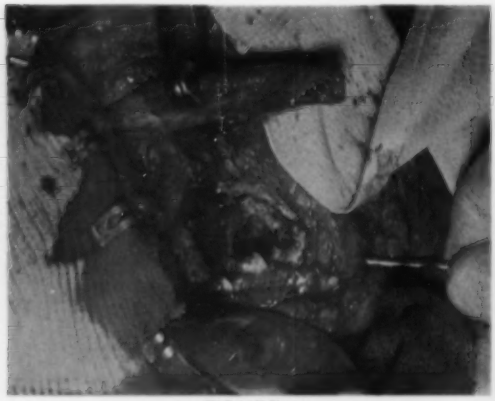

FIGURE 4.

FIGURE 5.

Figure 4: Trimmed distal fragment at left. Hole in proximal fragment.

Figure 5: Distal fragment (male) inserted in proximal fragment (female). Abductor attachment held in forceps being shifted distally on shaft.

Figure 6: Postoperative radiograph following removal of cast.

Note, in the preceding illustrations, how color defines tissue differentiations, helps explain each step in the surgical procedure.

FIGURE 6.

RADIOGRAPHS and photographs such as these are invaluable in teaching and research. Today, tomorrow, and for years to come, they will let others—students, associates, readers of publications—see what the radiologist saw, how the surgeon proceeded . . . see for themselves exactly what happened. The cost, however, is trifling in terms of the benefits.

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*Hollander, J. L.; Brown, E. M., Jr.; Jessar, R. A.; Udell, L.; Cooperband, S.; and Smukler, N. M.: Arth. & Rheum. 2:513 (Dec.) 1959.

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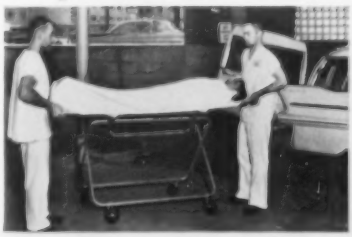

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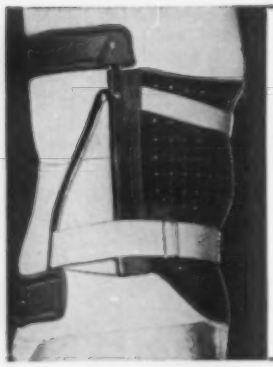

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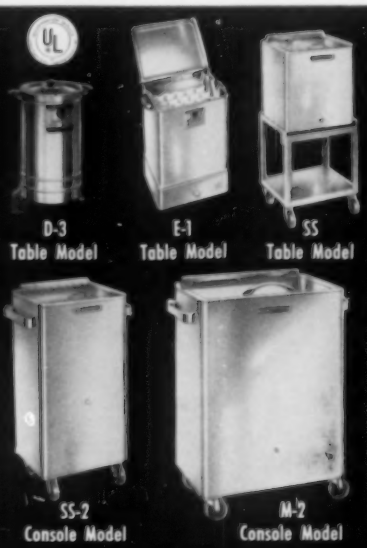

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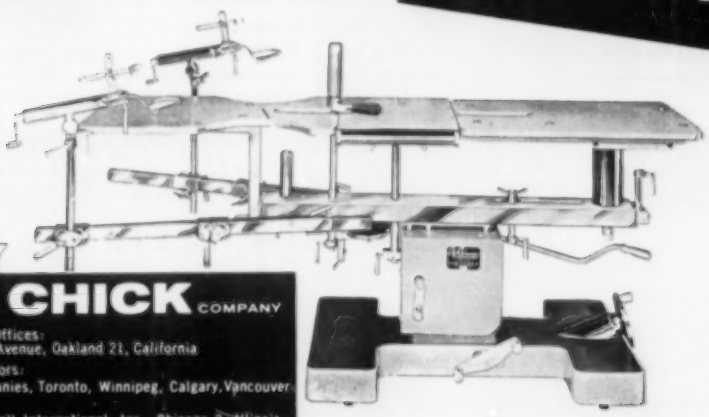

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